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NEW METHODS FOR THE DETERMINATION OF THE AVAILABILITY OF NITROGEN AND PHOSPHORUS TO PLANTS[1]

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IF a grower could find out in time what plant nutrient is lacking to make his crop do best, it would be a great help. The preliminary work reported here was an attempt to use simple tests requiring only a few minutes to determine deficiencies in the plant, and to determine whether these tests are reliable indicators of the ability of the soil to furnish nitrogen and phosphorus to the plant.

It was assumed that the nutrients found in the lower conducting tissues of the plant are a close approximation of the materials the plant is able to obtain from the soil, whereas the nutrients found in apical tissues would be such as had not been utilized or elaborated in the process of growth. Inasmuch as the nutrients derived by a growing plant from the soil must enter in solution through the stem, it seems reasonable that the concentration of a given nutrient in the conducting tissue of the stem should be directly proportional to the available supply of that nutrient from the soil. A measure of the content of nutrients in this conducting tissue, therefore, may be a better measure of the ability of the soil in which the plant is growing to supply nutrients than a chemical test of the soil itself. It seems probable, also, that an optimum content of nutrients in this kind of tissue should exist for the various stages of growth of each kind of crop regardless of the kind of soil in which the crop is growing. The work reported in this paper was done to test this hypothesis. The results are favorable and seem to justify thorough investigation of the question.

REASON FOR USE OF SOLUBLE N INSTEAD OF NITRATE N

The methods of analysis used were mainly those already described,[3] but with an important addition. Inasmuch as recent work has shown

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[3]EMMERT, E. M. Field method for estimating nitrate, phosphate and potassium in plants. Plant Phys., 7:315–321. 1932.

that other nitrogen compounds than nitrate may be absorbed and used by plants, it is proposed to substitute for the determination of nitrate, a determination of nitrogen in compounds soluble in 2% acetic acid, or "soluble nitrogen." The procedure for this determination is described below, and it was used in the analysis of lettuce reported herein.

DETERMINATION OF SOLUBLE NITROGEN

1. *To make the extract.*—Macerate thoroughly 1 to 5 grams (depending on the concentration of nutrients) of mature conducting tissue with a few tenths of a gram of acid-extracted charcoal[4] and exactly 10 cc of 2% acetic acid, and filter. Enough charcoal should be used to give a clear solution.

2. *The determination.*—Put 0.2 to 0.5 cc of the extract (depending on the amount needed to give a good color) into an ordinary 25-cc test tube. Add a granule of sodium chlorate about the size of a grain of wheat. From a pipette add rather rapidly 0.4 to 1.0 cc of fuming sulfuric acid (15% SO_3). The solution should boil and evolve chlorine. Excess of chloric acid must be decomposed or off-color tints will develop. It is decomposed if the solution boils vigorously and no chlorate is isolated on the sides of the tube. Blow and shake out the chlorine. As soon as the solution is clear add 0.2 to 0.5 cc of phenoldisulfonic acid and allow to stand a few seconds. Now add about 10 cc of water, neutralize with 40% sodium hydroxide until the maximum yellow color is produced, and make to 20 cc. Compare the color with a standard.

PRACTICABILITY OF THE TESTS

The soluble nitrogen and phosphate tests may be made in 5 to 10 minutes in the field. No heat or complicated equipment is needed. Besides test tubes, two reagents, a mortar and pestle, a funnel, and filter paper are needed for the extraction. For making the tests, a pipette, test tubes, and three reagents for soluble nitrogen and two for phosphorus are needed. Some scheme for comparing the color with the optimum color as determined for the particular crop being tested must be worked out. Experience is necessary to know what the colors should be. Once the optimum colors are determined for the various stages of a particular crop, it should be the same in all localities and for all types of soil. Calibration and modification to fit each type of soil, as is necessary with soil tests, should be unnecessary.

The part of the plant to be used will depend on the character of the growth. In all cases it should be a part which contains the most mature conducting tissue present. Of course a given part of the plant must be used in making comparisons, since various parts differ in their nutrient and moisture content.

The first important step is to determine the optimum, concentrations of nutrients for each stage of growth in the various crops.

RESULTS

Although there is some fluctuation in the data presented in Tables 1 and 2, the variations are not as large as the differences in soil type or fertilizer treatment. The data seem to show: (1) That soils of different

[4]EMMERT, E. M. A method for the rapid determination of phosphate in fresh plant tissues. Plant Phys., 5:413–417. 1930.

type differ widely in their capacity to furnish nitrogen and phosphorus to the conducting tissues of the plant; (2) that there is a correlation between the amount of nitrogen and phosphorus present and the yield; (3) that the effects of fertilizer treatments are shown by the tests on the plant; (4) that application of phosphate is accompanied by an increase in the amount of nitrate nitrogen in conducting tissues; and (5) that application of nitrate is accompanied by a reduction of phosphorus in the conducting tissues.

TABLE 1.—*Tomatoes, fall of 1932, in the greenhouse.**

Yield per plant, grams	Nutrients in petioles		N ÷ P	Kind of soil	Fertilizer in tons per acre†	
	Nitrate N, p.p.m.	Phosphate P, p.p.m.			Nitrate	Phosphate
1,767	551	222	2.5	Brown loam	0.20	0.35
1,476	844	342	2.5	Black loam	1.10	0.60
1,425	444	273	1.6	Black loam	0.00	0.00
1,397	764	152	5.0	Brown loam	0.40	0.25
1,340	731	75	9.7	Brown loam	0.60	0.00
1,283	632	266	2.4	Black loam	0.70	0.45
1,254	743	240	3.1	Black loam	0.63	0.30
1,026	755	39	19.4	Red clay	0.20	0.35
969	306	138	2.2	Brown loam	0.00	0.00
912	593	118	5.0	Sandy loam	0.40	0.50
884	704	28	25.1	Sandy loam	0.60	0.00
827	772	25	30.9	Red clay	0.50	0.00
799	684	122	5.6	Sandy loam	0.60	0.30
770	627	129	4.9	Red clay	0.20	0.65
656	152	38	4.0	Sandy loam	0.00	0.00
371	137	49	2.8	Red clay	0.00	0.00

*Average of 20 determinations throughout the growing season.
†Sodium nitrate and superphosphate, 16% P_2O_5.

The interrelationship of nitrogen and phosphorus appears noteworthy. It seems probable that increases of nitrate in the plant when phosphate fertilizers are used may be due to stimulation of bacterial action and nitrification. Although nitrate fertilizers do not influence the availability of phosphorus from the soil, the occurrence of increased nitrate in the plant probably stimulates the utilization of phosphorus. Thus, the phosphorus content in the conducting tissues would be found to be relatively low when the concentration of nitrate is high and relatively high if nitrogen is limiting growth. Despite variations due to utilization of phosphorus, it seems possible to deduce which element is limiting by making comparisons with the nitrogen-phosphorus concentrations found to accompany optimum production. Tests for both elements seem to be necessary before an interpretation can be made.

From data thus far obtained on nutrient levels in the plant at various stages of growth (detailed data are not presented here), it would seem that the optimum levels for high yields of tomatoes and lettuce would likely fall fairly close to the values given in Table 3 in p. p. m. of the enlarged portion next to the main stem of green lower tomato petioles and lettuce midrib tissue at given stages of growth.

TABLE 2.—*Lettuce, average of two crops, in the greenhouse.**

Yield per plant, grams	Nutrients in the midribs: Soluble N, p.p.m.	Nutrients in the midribs: Phosphate P, grams	N ÷ P	Kind of soil	Sodium nitrate, tons per acre†
89	848	131	6.5	Black loam	0.0
87	1,049	152	6.9	Black loam	0.1
86	937	167	5.6	Black loam	0.0
86	1,058	139	7.6	Black loam	0.0
66	844	54	15.6	Brown loam	0.1
62	1,021	46	22.2	Brown loam	0.2
60	662	74	8.9	Brown loam	0.0
55	619	44	14.1	Red clay	0.1
54	571	45	12.7	Brown loam	0.0
45	683	55	12.4	Sandy loam	0.1
42	755	18	41.9	Red clay	0.2
40	375	63	6.0	Red clay	0.0
35	394	88	4.5	Sandy loam	0.0
33	468	42	11.1	Sandy loam	0.0
32	872	29	30.1	Sandy loam	0.2
31	346	21	15.5	Red clay	0.0

*Average of six determinations for fall of 1933; eight for winter of 1933–34.
*Lettuce was grown on the tomato plats so that the treatments for tomatoes may have been still exerting an effect, especially phosphate.

TABLE 3.—*Favorable levels in the conductive tissue.*

Growth period	N of nitrate, p.p.m.	P of phosphate, p.p.m.	N/P
Tomatoes			
Early (about 12 inches high)	1,000–1,500	200–300	5
Medium (fruits set)	700–800	350–400	2
Late (fruits ripening)	300–350	300–350	1
Lettuce*			
Early (3–4 inches high)	1,500–2,000	150–200	10
Late (6–8 inches high)	800–1,000	100–125	8

*The results on nitrogen in lettuce are in p.p.m. of soluble nitrogen, not nitrate nitrogen.

PARTIAL CORRELATION COEFFICIENTS

In order to show the correlation between yield and the soluble nitrogen and phosphate phosphorus found in the mature conducting tissues of the plant, a statistical analysis was made using, Fisher[5] and Snedecor[6] as guides.

Several statistical values were determined, but only the partial correlation coefficients are presented since they best show the relation to yield. They have the advantage of showing the correlation between one factor and yield, the other factor being constant.

[5]FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1933.

[6]SNEDECOR, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press. 1934.

All the data available at the time were used in computing these values and the number of determinations used is shown in Table 4. For instance, 640 determinations were used in the fall crop of tomatoes. This means that the 32 plats were sampled 10 times in duplicate. Four samplings were made in October ("early" column), four in November ("medium" column), and two in December ("late" column). The averages for each month were computed and were used in the correlation calculations. All long additions and multiplications were checked on a Marchant electric machine and a slide rule, Barlow's tables, and logarithms were used to check other calculations.

CORRELATIONS WITH YIELDS OF TOMATOES

Table 4 presents the partial correlation coefficients determined in the statistical analysis. The correlation of tomato yields with phosphate phosphorus is very high, gradually decreasing from 0.82 to 0.58 at the end of the crop. The lower correlation of 0.39 for the spring crop, early period, shows either that other factors were more important or that the experimental error was more in the small number of cases used. The correlation is significant, however.

It is regretted that other duties did not permit more determinations to be made. It is highly significant that the correlation with available nitrogen falls from 0.75 to 0.06 with the advent of the fruit setting period and continues low in the late stages. High amounts of nitrogen in the conducting tissues are not conducive to fruit set in tomatoes.

During the early period, when the drain on nutrients was very heavy in attaining plant size and nitrogen, as well as phosphorus, was needed in large amounts, an inverse correlation (— 0.49) between soluble nitrogen (nitrate nitrogen with tomatoes) and phosphate phosphorus was obtained, showing that as one element became limiting, the other tended to accumulate. This relation was not evident later in the fall crop, nor in the spring crop, since a partial correlation of 0.35 is required to be significant when $n = 29$ and using $P = .05$, according to Fisher's Table V.

CORRELATIONS WITH YIELDS OF LETTUCE

The partial correlation coefficients for lettuce do not run as high as with tomatoes. This is due, partly at least, to the difficulty in getting uniform samples of lettuce. The enlarged portion afforded a uniform sample next to the main stem of the lowest petiole of the tomato. In the case of lettuce, it was necessary to separate the midrib from leaf tissue. This gave a chance for some variation. Often the lowest leaf was small and several leaves were required, giving more chance for variation. However, most of the values are significant when yields are considered, soluble nitrogen especially giving several high coefficients.

In the fall crop, soluble nitrogen and yield gave 0.610 in the early period and dropped to 0.245 late in the growing period. Phosphate phosphorus rose from 0.486 early in the growth to 0.563 late in the season. In the winter crop, no samples were taken in the late period, but the middle period showed high coefficients, jumping from 0.565,

TABLE 4.—*Partial correlation coefficients between yield and soluble nitrogen and phosphate phosphorus found in the mature conducting tissues of the plant.**

Crop and season	No. of determinations	Yield and phosphate, soluble nitrogen constant			Yield and soluble nitrogen, phosphate constant			Soluble nitrogen and phosphate, yield constant		
		Early	Medium	Late	Early	Medium	Late	Early	Medium	Late
Tomatoes, fall, 1932†	640	0.824	0.724	0.583	0.751	0.062	0.200	—0.49	0.251	—0.053
Tomatoes, spring, 1933†	128	0.389	—	—	0.457	—	—	0.047	—	—
Lettuce, fall, 1933†	192	0.486	—	0.563	0.610	—	0.245	0.069	—	0.050
Lettuce, winter, 1933–34†	256	0.240	0.574	—	0.565	0.704	—	0.217	—0.230	—
Cucumbers, spring, 1934	160	0.418	0.265	0.085	0.318	0.441	—0.077	—0.472	—0.331	—0.247

*When n = 29, the correlation is significant at 0.35 (Fisher's Table V).
†Detailed data used in the calculations are presented in Kentucky Station Circular No. 43.

early, to 0.704 for soluble nitrogen, and from 0.24 to 0.574 for phosphate phosphorus. There was no significant relation between nitrogen and phosphorus in the lettuce results. It is apparent from this that it is important to keep both nitrogen and phosphorus high up to the late stages of growth. Maintaining high soluble nitrogen seems to be even more important for lettuce than high phosphate.

CORRELATIONS WITH YIELDS OF CUCUMBERS

The partial correlation coefficients for cucumbers were not so high as for tomatoes and lettuce. Probably two other factors contributed to the coefficients for which it was not possible to correct. First, the cucumber is especially affected by water relations, both in the soil and in the air. Although efforts were made to keep this factor uniform, the soils dried out so rapidly from the heavy growth of foliage that on the raised benches it was impossible to keep the soils from drying out unevenly. There were some variations in air humidity, also, in different sections of the house.

Second, the growing season was rather long and the latter part of the growth occurred in June and July when the temperatures were so high in the greenhouse as to prohibit normal growth. However, in the early growth stages, the coefficients are significant for phosphate and practically so for soluble nitrogen. In the medium growth stages, soluble nitrogen gave the highest coefficient of yield correlation (0.441). None of the coefficients are significant in the late, high-temperature period. It is interesting that there was a fair inverse correlation between phosphorus and nitrogen in both the early and medium growth periods. Contrary to what would be expected from the results with tomatoes, soluble nitrogen seems to be even more important than phosphate in setting cucumber fruits, while phosphate is important in gaining plant size in the early stages of both cucumbers and tomatoes.

RELATION OF PRECIPITATION TO MOISTURE STORAGE AND CROP YIELD[1]

A. F. BRACKEN AND P. V. CARDON[2]

IT is generally recognized that soil moisture with its various practical and fundamental relationships is the most important single factor connected with the profitable utilization of western dry-farm land. With a cropping system of alternate wheat and fallow, such as is necessary because of the distribution of the limited rainfall, the problem of successful wheat growing, so far as it can be controlled by the farmer, is one of moisture accumulation and conservation. The particular phase of the problem dealt with in this study is that of measuring the percentage of rainfall saved in the soil over a whole period of a fallow-crop cycle and fraction of a cycle as related to water cost of crop production. The results reported represent accumulated data from the Nephi Dry-Land Substation, Nephi, Utah, from 1909 to 1918 and from 1925 to 1933, both inclusive.

ENVIRONMENTAL FACTORS

Since soil type, altitude (5,300 feet), evaporation, temperature, wind, and total amount and distribution and precipitation are all definitely associated with the efficiency of rainfall in relation to yield, it is necessary to state measurements which have been made of these various factors. The soil is classed as a clay loam, reddish-brown in color, and uniformly 10 feet or more in depth with a nitrogen content of 0.1% in the surface foot. The average moisture equivalent to a depth of 6 feet is approximately 24%. Table 1 gives the average wind velocity, evaporation, and mean temperature for each of the seven months from April to October, inclusive, since 1908.

TABLE 1.—*Average wind velocity, evaporation, and mean temperature, April–October, 1908–1933, inclusive.*

	April	May	June	July	Aug.	Sept.	Oct.	Total
Wind, miles per hour	4.1	3.9	3.8	3.3	3.2	3.2	3.1	—
Evaporation, in.	3.898	6.545	8.730	9.547	8.733	6.367	3.532	47.352
Temperature, °F.	44°	53°	63°	71°	70°	61°	48°	—

The mean monthly and yearly average rainfall for the period since 1898 is given in Table 2.

[1]Contribution from Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by Director, October 19, 1934. Received for publication October 26, 1934.

[2]Superintendent and Director, respectively, Nephi Dry-Land Substation. The writers acknowledge their indebtedness to F. D. Farrell, Kansas State Agricultural College, Manhattan, Kan.; A. D. Ellison, Belle Fourche, S. D.; and J. W. Jones, U. S. Dept. of Agriculture, Washington, D. C., all of whom, as superintendents of the Nephi Dry-Land Substation, directed and conducted the early work in this investigation. Credit is also due the following field foremen for their efforts in taking samples and in otherwise assisting in the work: Stephen R. Boswell, Nephi; James A. Eagar, now with the Plant Introduction Gardens of the Bureau of Plant Industry at Ship Rock, New Mexico; and the late I. J. Jensen of Moccasin, Mont.

TABLE 2.—*Average precipitation in inches, by months, 1898–1933, inclusive.*

Precipitation in inches												
Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1.09	1.19	1.53	1.33	1.56	0.57	0.84	0.93	0.91	1.15	0.90	1.02	13.05

METHODS

In this study, 12 1/10-acre plats, scattered at random over a part of the experimental field and serving as checks in various moisture experiments, were used. While six of the plats were in crop, the other six were in fallow. Tillage and seeding treatments were uniform for all plats. Moisture determinations were made by taking five samples from each plat to a depth of 6 feet with a King soil tube. The samples were then dried in a gas soil oven for a period of 12 hours at a temperature of approximately 110° C. Soil-moisture percentage was determined on the basis of the dry weight of soil.

RESULTS

RELATION OF PRECIPITATION TO MOISTURE STORAGE

Under an arrangement of alternate crop and fallow, for all practical purposes, conservation of moisture has a simple solution. It consists of merely plowing the land either in fall or early spring with only sufficient tillage given during the fallow period to control weeds. The percentage of rainfall which can be stored, however, even by following the best of tillage practices, varies greatly from season to season, as indicated by results given in Table 3. This table is divided into four parts, the first three of which represent definite fractions of a fallow-crop cycle. The first winter with plowing deferred until spring might be called the beginning of the fallow. In the fall of this period, moisture determinations were made and repeated again the following spring. The difference between the two represented the gain. Knowing the amount of precipitation between the two dates of sampling, the percentage of rainfall stored as soil moisture was calculated. The summer is commonly known as the season of summer fallow. Having moisture determinations for spring and fall, the percentage gain or loss was determined. The second winter of the cycle is that period during which another crop of winter wheat is starting growth. By taking soil samples in the spring of this period, the percentage of rainfall stored and the amount available to crop use were calculated for this fraction as well as for the whole fallow-crop cycle.

Table 3 is divided into two divisions, the first covering the period from 1909 to 1918 and the second from 1925 to 1933, each inclusive. For the first division, the tests were concerned only with soil moisture. Sampling was usually done about May 1 and again soon after removal of the crop—not later than September 15. For the second division, the study was conducted to determine the relationship between soil moisture and nitrate accumulation. The first samples for the latter were taken just as early as it was possible to get on to the land before the plants had used any appreciable amount of moisture,

except in seasons of fall emergence—in all cases not later than April 20. The last samples of the season were collected near November 1.

An examination of the data in Table 3 reveals the fact that apparently a larger percentage of precipitation was found in the upper 6 feet of soil after the first winter of the fallow-crop period than for any other fraction of the entire cycle. For the first division (1908–18), an average of 56.6% of the precipitation was conserved as soil moisture and for the second division (1925–33), 69.2%. This variation was due to the difference in time of taking samples, allowing a long winter period for the first and a shorter period for the second division of the study. On a sandy loam soil for a similar period, Widtsoe (10)[3] reported an average saving of 79.4% of the precipitation, with a range varying from 64.8 to 95.56%.

TABLE 3.—*Rainfall and percentage of rainfall saved in the soil over a whole period of a crop cycle and fraction of a crop cycle.*

Crop cycle	Rainfall in inches and precipitation in per cent conserved in soil over fallow-crop period							
	1st winter, land in stubble		Summer, fallow spring-plowed		2d winter, winter wheat fall-sown		Whole cycle	
	Amt., in.	Stored %	Amt., in.	Stored %	Amt., in.	Stored %	Amt., in.	Stored %
1909–1911......	8.03	22.2	2.88	10.0*	7.13	29.2	18.04	11.6
1910–1912......	10.02	35.6	4.41	5.9*	6.48	65.2	20.91	31.8
1911–1913......	8.61	66.4	2.29	0.1	8.17	30.9	19.07	44.5
1912–1914......	9.11	65.6	3.92	10.9*	12.77	6.6	25.80	19.1
1913–1915......	13.08	54.0	4.22	14.8*	8.35	11.5	25.65	20.5
1914–1916......	8.96	69.7	4.70	0.1	9.20	20.3	22.86	36.0
1915–1917......	9.20	76.5	2.88	8.5*	6.52	32.5	18.60	41.0
1916–1918......	6.18	62.7	5.64	0.5*	7.44	41.4	19.26	32.1
Average......	9.15	56.6	3.88	6.1*	8.26	29.7	21.27	29.5
1925–1927......	5.55	73.1	4.04	26.1*	9.16	36.3	18.75	16.8
1926–1928......	9.16	49.4	3.49	16.8*	7.47	48.2	20.12	28.9
1927–1929......	7.47	76.6	4.10	12.6*	5.52	32.6	17.09	33.2
1928–1930......	6.52	75.0	8.92	0.3	6.17	49.4	21.61	28.4
1929–1931......	6.17	80.6	10.91	0.5	3.21	17.4	20.29	30.9
1930–1932......	3.21	46.0	2.93	7.7	6.72	71.4	12.86	39.5
1931–1933......	6.72	83.8	5.22	11.0*	3.65	60.7	15.59	39.7
Average......	6.40	69.2	5.66	10.5*	6.13	45.1	18.19	32.5

*Percentage of soil moisture lost during the summer fallow period not counting summer precipitation.

Correlation:

Rainfall (in.) to percentage rainfall stored over 1st winter after crop... $r = -.214 - P < 0.1$

Rainfall (in.) to percentage rainfall stored over 2d winter of crop year... $r = -.437 - P < 0.1$

Rainfall (in.) over whole period to percentage stored. $r = -.371 - P < 0.1$

[3]Figures in parenthesis refer to "Literature Cited," p. 20.

During the second winter the results show that an average of 29.7 and 45.1% of the precipitation, for the first and second sections, respectively, was available for plant use at the time samples were taken in the spring of the crop year. This difference likewise can be partly accounted for by there being a longer period between fall and spring sampling dates for the first division than was the case for the second part of the study. In addition, it is apparent that through later spring sampling a certain amount of soil moisture absorbed from rainfall would be used by the plants previous to making moisture determinations. When soil samples were gathered early in the fall, such as happened from 1909–11 to 1916–18, the same thing would also occur in seasons of early emergence of wheat stands. This happened in the falls of 1910, 1913, 1914, and 1916, which were in the crop cycles of 1909–11, 1912–14, 1913–15, and 1915–17, respectively.

In addition to this source of error, which partly accounts for the difference between the second winter periods of the first and second sections of the study, another error occurred which can be partly corrected. It will be observed that the low percentages of the second winter, beginning with 6.6 for the 1912–14 cycle, are grouped together in successive order over a period of high rainfall. From a detailed examination of moisture data covering the first winter, it has been found that water from rain and melting snow seldom penetrates the soil to a depth beyond 6 feet. For the second winter, especially during the seasons of higher precipitation such as occurred in the cycles of 1912–14, 1913–15, and 1914–16, increases in soil moisture for other tests with deeper sampling were measured down to 10 feet. Using these results as a basis for adjustment, 6.6% becomes 23%, 11.5 changes to 36, 20.3 increases to 32, and 36.2 is substituted for the average of 29.7%. If these same changes are carried through to the percentage of rainfall stored for the whole fallow-crop cycle, then 19.1, 20.5, and 36.0 become 27.3, 28.4 and 41.2%, respectively, with the average of 29.5% increasing to 32.2%. It is improbable from data available, depending upon intensity and distribution of rainfall, that any appreciable percentage of moisture moves down much below the 6-foot level when the total precipitation for the fallow-crop period amounts to 20 inches or less.

As previously indicated, the data in Table 3 show that a greater percentage of rainfall was conserved in the upper 6 feet of soil for the first winter than for either the summer period or the second winter of the fallow-crop cycle. In observing the rather marked variation between the first and second winters, it is clear that two different years are used. For example, the winter of 1909–10, the first winter of that particular cycle, is compared to the second winter of 1910–11 in the same cycle, and so on throughout the entire study. In order to make the comparison direct for the same season, the data for the last division of Table 3 have been rearranged and are given in Table 4. As shown by the averages, no significant change has been made in the results as compared to the arrangement given in Table 3.

The higher percentage of rainfall found in the upper 6 feet of soil at the end of the first winter as compared with that at the end of the second winter of the fallow-crop cycle is due to a number of factors. A

part of the difference, and a major part, especially in those seasons of early fall emergence of the crop, might be accounted for in the use of moisture by the growing plants. This occurred in the cycles of 1909–11, 1912–14, 1913–15, 1915–17, 1926–28, and 1929–31. As already explained, this likewise accounts for a part of the difference between the second winters of the first and second sections because of later spring sampling for the period from 1909–11 to 1916–18, inclusive. Movement of moisture to levels below 6 feet, the depth to which samples were taken, also offers an explanation for a part of the difference. This has already been mentioned in connection with the variation between the first and second sections.

TABLE 4.—*Percentage of precipitation stored in soil for stubble land and land fall seeded to winter wheat.*

Winter period	Rainfall, in.	Water stored	
		Stubble %	Crop %
1926–27	9.16	49.4	36.3
1927–28	7.47	76.6	48.2
1928–29	6.52	75.0	32.6
1929–30	6.17	80.6	49.4
1930–31	3.21	46.0	17.4
1931–32	6.72	83.8	71.4
Average	6.54	68.6	42.5

For the second winters of the 1911–13, 1916–18, 1925–27, 1927–29, 1928–30, and 1931–33 cycles, other factors, however, were likely responsible for most of the differences shown. In all of these seasons the crop failed to emerge before winter which precluded the possibility that the plants had used any great quantity of stored moisture before the samples were taken in the spring and, because of the lower amount of rainfall, no appreciable amount had moved much below 6 feet as indicated by samples taken 10 feet deep.

It has been observed that land in wheat after the snow leaves the ground is usually more compact than that in stubble, thus tending to favor a more rapid drying out of the surface, particularly, from a soil supporting plants not beyond the second and third leaf stage of growth. Associated with this condition, the stubble partly standing and partly lying down apparently seems to shade the ground more efficiently than untillered plants. It has also been noticed that a stubbled surface, associated usually with the characteristic looseness, serves as a more efficient barrier in uniformly preventing runoff of rapidly accumulating water from melting snow than a surface with plants just starting to develop. These latter factors, operating singly and in conjunction, are probably responsible for most of the variation between the first and second winter periods of the fallow-crop cycle, especially, as pointed out, when the plants are untillered up until the soil samples are gathered in the spring for moisture determinations.

Thus, it may be concluded, that the smaller percentage of rainfall found in the spring at the end of the second as compared to the first winter of the fallow-crop cycle in the upper 6 feet of soil was due to a

combination of factors, as follows: (a) Use of the stored water by the growing wheat limited mainly to seasons when stands emerge in early fall soon after seeding; (b) movement of moisture below the 6-foot level, especially in those seasons of high rainfall; (c) greater tendency for evaporation because of the condition of the surface; and (d) increased chances for loss by runoff, the last two limited principally to seasons when the crop is late in emerging.

After attempting to explain the difference in percentage of moisture saved in the soil between the first and second winters of a fallow-crop period, it is obvious that a significant loss occurred in excess of this variation. Despite the fact that runoff and evaporation are probably lessened by standing stubble and that moisture seldom moves below 6 feet in depth in the first winter of a fallow-crop cycle, an average of 56.6% of the rainfall, or 5.17 inches, was stored out of a total of 9.15 inches for the first period (1909–18) and 4.43 inches, amounting to 69.2%, was stored out of an average total amount of 6.40 inches for the second period.

This loss is likely limited mainly to two sources—runoff and evaporation. Runoff seldom happens on stubble land previous to spring plowing, although loss from this source occurs occasionally, especially in springs when the soil has been frozen to considerable depth previous to being covered with winter snow. If the snow melts before frost leaves the ground, runoff becomes excessive. This was observed in the spring of 1919, which, however, is not included in this study. Rapidly melting snow, with water accumulating faster than can be absorbed by the soil, may be associated with loss by runoff, although any appreciable waste from this source is infrequent. The chief source of loss is probably due to evaporation.

In the South Plains region, Finnell (6) found that 65.8% of the rainfall evaporated from the surface during and immediately following precipitation. While these measurements were made in an area receiving the major portion of rainfall during the summer, and, therefore, can hardly be compared with measurement from the area under consideration, still the results show the importance of this source of loss. Very little evaporation occurs during the winter while the ground is covered with snow. Observations made elsewhere in Utah indicate that this source of loss amounts to less than 0.5 inch, extending from the latter part of November until about March 1. The greatest evaporation of moisture reserves for the winter period occurs in late fall and early spring, especially in the spring when the surface soil is saturated from melting snow and rain. It is not uncommon for this condition to continue from the time snow has melted until May 1, or thereabouts. It is observed from Table 1 that the evaporation for April from a free-water surface measures 3.898 inches. Fortier (7) reports an average weekly evaporation of 4.75 inches from a wet soil and 1.88 inches from a water surface under similar atmospheric conditions. This measurement was made when the mean air temperature in the shade registered 71° F. No data are available to show the comparative relationship of evaporation from a free-water surface and a saturated soil as influenced by a variation of temperature. The conclusion, however, might be drawn that for April, with a mean temper-

ature of 44° F, the evaporation from a saturated soil surface should equal or be slightly greater than that from free water. If the same ratio as exists between April and May can be applied to March and April, the evaporation for March from a free-water surface would measure 2.326 inches. This added to 3.898 inches for April equals 6.334 inches. It is not implied that this can be compared directly with what happens in the soil. The various relationships are far too complex with alternate freezing, thawing, and drying, changes in humidity, and clear and cloudy days, but the data, as well as inferences drawn from the results, lead to the conclusion that evaporation might be considered the major factor connected with losses of moisture during winter periods extending from the latter part of October to the latter part of April.

The summer rainfall of the Great Basin, amounting to approximately one-fourth of the total amount for the year, is ineffective in building up soil moisture reserves (Table 3). The summer storms usually occur either as light sprinkles of rain or as heavy torrential showers. The light rains are lost almost immediately by evaporation and the heavy showers fall so suddenly that at times a large portion runs off, carrying away some of the surface soil. Widtsoe (10) reports an observation made by Farrell in which 2.6 inches of rain fell in 4 hours. The surface of the fallowed land became so packed that only 0.25 inch, or less than one-tenth of the whole amount, soaked into the soil. Similar observations were made in 1929 and again in 1930, when the summer rainfall was far above the average (Table 3). When the surface is dry, a rain of 0.5 inch or less is of no value whatever in storing moisture, but in rainy periods when light showers come so close together that the surface soil is wet from one storm to another, even rains small in amount may penetrate below the surface. But it must be stated that, even though light showers fail to add anything to the soil moisture reserves, such storms are of value to growing crops and, to some extent, help to reduce evaporation from the soil.

On the Plains where the major part of the precipitation falls during the summer, Burr (3) found that 10 to 33% of the rainfall was saved over one winter and during the following summer up until time for seeding in the fall. Taking the same portion of the fallow-crop cycle from Table 3, an average of 33.8 and 26% of the rainfall for the respective 8- and 7-year periods was saved. Finnell (6) found that from 22 to 39% of the total rainfall of a wet period in the South Plains may enter the subsoil, with approximately 20% of the normal precipitation being saved for crop growth.

An examination of the detailed results for the summer period (Table 3) leads to the conclusion that no direct relationship exists between percentages of moisture lost or saved during the fallow period and amount of summer precipitation. It is the character of the storms which governs summer losses rather than the sum total. The summer rainfall in 1910 measured 2.88 inches, and without considering this 10.1% per cent of soil moisture which the soil contained in April of that spring was lost. The storms came as scattered showers with no storage. Similarly, the seasons of 1913, 1914, 1916, 1927, 1928, 1931, and 1932 were summer periods of scattered rains limited in amount.

For the fallow period of 1911, with 4.41 inches of rain, the storms were scattered but were of such a nature that loss from the soil was reduced to 5.9%. The seasons of 1915 and 1917 were of like character. The 2.29 inches of rain which fell in the summer of 1912 came in one or two heavy storms early in the season, thus entering the soil. For the fallow period of 1926, which was in the fallow-crop cycle of 1925–27, in the spring the soil contained an average of 17.6% moisture to a depth of 6 feet, while the fall sampling showed only 13%. After the late spring rains, amounting to 4.04 inches, summer and fall were seasons of protracted dryness and warmth.

The summer periods of 1929 and 1930 were epoch making in changing dry-land tillage for the Great Basin area. Previously, it was customary to level and harrow spring-plowed land soon after the plowing was finished, with additional harrowings during the summer. This left a smooth well-tilled surface. Under average summer conditions approximately 10% of the moisture contained in the soil at spring sampling time is lost by fall. If this is subtracted from the moisture percentages for 1929 and 1930, then it can be assumed that 19% and 20% of the 8.92 inches and 10.91 inches of precipitation for these two seasons, respectively, entered the soil to be stored for crop use. Part of the remaining portion was lost by evaporation, but because of the torrential character of the storms and because of the smoothness of the surface, a large percentage was lost by runoff, carrying with it a part of the soil, in places to the full depth of plowing.

A recent unpublished fertility survey of two typical dry-farm areas in Utah discloses the fact that approximately 20% of the nitrogen and organic matter reserves have been lost from the soil, part of this loss no doubt occurring from erosion. Since Harris and Jones (8) found that rough untilled spring-plowed fallow with weeds hoed off conserved as much moisture as did fallow which received normal tillage, and since Bracken and Stewart (1) report no difference in yield between plats similarly treated, farmers are now advised to let spring-plowed land lie rough and untilled until after the period of summer showers; however, weeding may be necessary. This practice not only saves labor and expense, but may also aid in conserving soil moisture as well as soil.

The correlations at the bottom of Table 3 show the relationship between rainfall and amount of precipitation stored in the soil. Because of there being only 15 years' results involved in this study, the individual correlations are not significant. Since all three are in the same direction, however, they do collectively indicate that the greater the rainfall, the less the proportionate amount stored.

From the foregoing discussion of results, the general conclusion might be drawn that precipitation is much more likely to increase soil moisture reserves when the weather is cool than during the summer when all of the dissipating forces are at the maximum.

RELATION OF PRECIPITATION TO CROP YIELD AND WATER COST OF CROP PRODUCTION

Yield of winter wheat on the dry lands of the Great Basin is a result of many factors, most important of which are distribution and

amount of precipitation. Early fall emergence of wheat stands is generally associated with high yields. This permits the development of a rooting system with a wide feeding range. Under such conditions plants produce most of their vegetative growth during the shorter and cooler days of the spring, maturing as dryness and warmth become more intense. If, on the other hand, vegetative development is forced into the hotter, dryer, and longer days of summer, through late winter or early spring emergence, it is usually at the sacrifice of yield. Late summer and early fall precipitation, therefore, is highly important to profitable dry-farm wheat production. The higher acre yields shown in Table 5, such as 30 bushels for 1911, 39.3 bushels for 1914, 31.1 bushels for 1915, 26.7 bushels for 1917, 25 bushels for 1928, and 23.9 bushels, are near the maximum when the seed fails to germinate before winter, and, according to the data in Table 5, acre yields ranged from this amount down to 6.8 bushels.

Wheat which is untilled on April 1 may suffer from a number of hazards which would otherwise not seriously affect well-developed stands. The plants may "crust under," as happened in the early spring of 1913. Low April temperatures, as unconducive to crop growth as to nitrate formation, may retard plant development. This occurred in 1927 and 1933. And drought, which usually becomes more acute with the advance of summer, can always be depended upon to reduce yields of late wheat. Chilcott (4) found that on the Great Plains where crop hazards are greater than in the area surrounding the Nephi Dry-Land Station, inhibiting factors to crop yield reduced production by approximately 48%. Using 30 bushels as an average maximum yield (as calculated from Table 5) and subtracting the averages from this figure, it might likewise be concluded that inhibiting factors reduced yields by 24 to 33%, respectively, for the first and second divisions of the study.

The correlations at the bottom of Table 3 also show that, in addition to total moisture and total rainfall, there are other factors which govern yield. It might be expected that the correlation of spring rainfall, covering the periods from April 1 to ripening time, should be higher and consequently more significant. The large yields of 1914, 1915, and 1917 were no doubt measurably increased by high spring rainfall, while the 30-bushel acre yield for 1911 was grown in a season of extremely low spring precipitation. It will also be observed that the low yields of 1918 and 1933 were produced in seasons of relatively high spring rainfall. The deficiency of a dry unproductive fallow associated with winter emergence of the crop cannot be remedied by high spring rainfall, yet it is recognized that without spring rain, late-maturing stands in certain seasons may result in partial failures.

In making an attempt to measure the water cost of dry matter and inches of moisture used for producing a bushel of wheat, it is realized from field studies that results cannot be exact because of the many factors involved which are beyond control. In spite of this fact, the calculations are helpful in interpreting some of the variations in production.

The water cost of dry matter, as shown in Table 5, was obtained by subtracting the amount of moisture remaining in the soil after harvest

TABLE 5.—*Total precipitation, total dry matter, water cost of dry matter, acre yields of wheat, and water cost of 1 bushel of wheat.*

Year	Total precipitation, in.	Total water, in.*	Water used by crop, in.			Total dry matter, lbs.	Water cost of dry matter, lbs.	Wheat yields, bu.	Acre inches water to 1 bu. wheat	No. bus. wheat to 1 in. water	
			Soil water	Spring rain†	Total					Soil water spring rainfall	Total water
1911	19.11	36.21	7.15	1.07	8.22	4,140	450	30.0	0.274	3.65	0.83
1912	22.16	26.56	7.36	1.25	8.61	1,852	1,053	14.7	0.586	1.70	0.57
1913	20.62	15.59	3.45	1.55	5.00	908	1,247	6.8	0.735	1.36	0.44
1914	29.40	32.32	5.78	3.59	9.37	5,230	406	39.3	0.238	4.20	1.22
1915	29.55	35.00	6.86	3.90	10.76	4,466	545	31.1	0.346	2.89	0.89
1916	24.11	22.01	6.23	1.25	7.48	2,119	800	17.5	0.427	2.34	0.80
1917	23.22	23.26	8.00	4.62	12.62	3,744	763	26.7	0.456	2.12	1.15
1918	22.04	23.13	7.28	2.76	10.04	1,979	1,149	15.7	0.639	1.56	0.68
Average	23.77	26.76	6.15	2.50	9.01	3,055	801	22.8	0.463	2.47	0.82
1927	20.24	30.24	6.37	1.49	7.86	2,210	805	16.0	0.468	2.13	0.53
1928	22.21	22.21	5.81	2.09	7.90	3,208	558	25.0	0.316	3.16	1.13
1929	19.70	20.50	5.00	1.61	6.61	2,690	556	20.3	0.334	2.99	0.99
1930	25.25	22.45	5.72	3.64	9.36	2,770	765	20.8	0.450	2.22	0.93
1931	21.06	21.15	6.55	0.77	7.32	3,700	448	23.9	0.306	3.26	1.13
1932	15.41	17.44	7.10	2.55	9.65	3,720	588	19.2	0.530	1.88	1.10
1933	19.97	22.25	6.92	4.38	11.30	2,080	1,231	15.9	0.711	1.40	0.71
Average	20.55	22.32	6.21	2.36	8.57	2,911	709	20.2	0.445	2.43	0.93

*Total water over fallow-crop cycle, including spring rainfall with correction for moisture reserves used from previous cycle and amounts remaining for crop use after harvest.

†Rain (in.) coming after soil was sampled up until ripening of crop.

Correlation:

Total water to acre-yield . . . . $r = .629$—$P = 0.01$

Total rainfall to acre-yield . . . . $r = .561$—$P = 0.02$

Spring rainfall to acre-yield . . . . $r = .394$—$P < 0.1$

to a depth of 6 feet from that found in the spring. This amount was then added to the rainfall (inches) which fell from the time of sampling to the beginning of ripening. The total pounds of dry matter were then divided into the total amount of water used. The acre inches of water used to produce a bushel of wheat and the bushels of wheat grown by each inch of soil water were similarly calculated. It is understood that in adding spring rainfall to the cost of crop production that storms too limited to reach the roots have been included. Light showers are of value, however, in that the atmosphere is cooled off, humidity is increased, and transpiration is decreased, thus making stored soil moisture more efficient in expressing itself in crop yield. The figures in the last column of Table 5 (bushels of wheat to each inch of total water) were obtained by using the total moisture as a basis. This includes total precipitation over the whole fallow-crop cycle with corrections for after harvest. Precipitation falling from time of spring sampling to beginning of ripening was added to this amount. The total was then divided into the acre yields of wheat.

The data given in Table 5 seem to point to the fact that the water cost of dry matter per unit quantity of water used and also acre inches of water to each bushel of wheat tend to decrease with the yield for the range of the moisture involved. The low acre yield of 6.8 bushels for 1913 was associated with the highest water cost of dry matter (1,247 pounds). This was followed by the highest yield shown in Table 5, *viz.*, 39.3 bushels, with 406 pounds as the water cost of dry matter, which was the lowest recorded.

The variety Turkey Red winter wheat (C. I. No. 2998) was grown during the first 8 years of this study and Utah Kanred was used during the second period. Briggs and Shantz (2), in a carefully controlled experiment at Akron, Colo., found the average water cost of dry matter to be 473.8 and 475.8 pounds, respectively, for Turkey C. I. No. 1571 and Kharkov C. I. 1583. It will be observed from Table 5 that, in seasons of high yield, the water cost of dry matter approximated the amounts found by these two investigators.

Hopkins (9), working at Swift Current, Saskatchewan, Canada, gave 489 pounds as the water cost of a pound of dry matter when wheat was grown on fallow lands and 764 pounds when wheat followed wheat.

Cole and Mathews (5) made a similar study with spring wheat, taking results from 18 Plains dry-land stations. The figures varied from 382 pounds with an acre yield of 56.5 bushels at Belle Fourche, S. D., to 3,208 pounds with an acre yield of 1.5 bushels at Assiniboine, Mont. At Edgeley, N. D., a 10-year average showed the water cost of dry matter to be 1,047 pounds. At North Platte, Neb., for a 9-year period the water cost was 980 pounds. In a 6-year test in Utah, Widtsoe (10) found that when wheat was supplied with sufficient water for normal growth, 1,048 pounds of water were required to produce a pound of dry matter.

Thus, it is evident that the cost of crop production in terms of water varies greatly. Most of the results within the limits of this experiment, i. e., on dry-farm lands show that high yields are usually associated with a low water cost, while low yields accompany a high water cost of

dry matter. At the Nephi Dry-Land Station a low water cost of dry matter is always associated with a productive fallow and early fall emergence of the crop. On the other hand, an unproductive fallow and late emergence of wheat stands, when rated in terms of water, are expensive.

The last two columns in Table 5 give the bushels of wheat produced by each inch of soil water plus spring rainfall and by each inch of rainfall when total moisture in inches is added to spring rainfall of the crop year. The figures for individual years show some variation, but, generally speaking, seasons of high yield are associated with high production per unit of water whether it be soil moisture plus spring rainfall or total rainfall. In the season of 1914, with a production of 39.3 bushels to an acre, each inch of soil water grew 4.2 bushels of wheat; for 1911, with an acre yield of 30 bushels, 3.65 bushels; and for 1928, with an acre yield of 25 bushels, 3.16 bushels were produced by each inch of soil water. In almost every case the seasons of low yield were associated with low production per inch of soil water plus spring rainfall. Widtsoe (10) calculated that each inch of soil water should produce 2.5 bushels of wheat. The averages of 2.47 and 2.43 bushels for each inch of soil water, respectively, for the first and second periods (Table 5) approximate this figure. Chilcott (4), in averaging results from all the Plains dry-land stations, found the ratio of yield to rainfall to be 0.981. Calculated in the same manner, the ratio for the first division of Table 5 was found to be 0.962 and for the second 0.983. When a correction was made to the rainfall for moisture reserves used from the previous crop cycle and amounts remaining for crop use after harvest, the ratios are 0.82 for the first and 0.93 for the second parts of this table.

SUMMARY

Because of the low rainfall in the Great Basin, with 75% falling during the fall, winter, and early spring months, a cropping arrangement of alternate wheat and fallow has come to be regularly practised on dry-farms.

From late October to the middle of April, 69.2% of the precipitation for the first winter and 45.1% for the second winter was conserved as soil moisture. Use of moisture by the growing crop, movement of water to depths beyond 6 feet, increased evaporation, and greater tendency for runoff have all contributed to differences between the first and second winters of a fallow-crop cycle. In addition to the variation between the first and second winters, a loss of approximately 30% occurred, due mainly to evaporation and occasionally runoff.

During the summer-fallow period rains seldom make any significant addition to the stored soil moisture.

Over a whole fallow-crop cycle approximately 30% of the precipitation was conserved.

High yields of dry-farm winter wheat in the Great Basin are directly associated with fall emergence. When plants fail to emerge before winter or early spring, the maximum yield is usually not more than 20 bushels. Late crops suffer greater hazards than earlier matur-

ing stands. The deficiency of late emergence usually cannot be remedied by high spring rainfall.

The water cost of dry matter and also the acre inches of water used in producing a bushel of wheat seemed to decrease with yield within the limits of the range of moisture involved. Taking an average of both divisions of the study, 756 pounds of water were used to produce a pound of dry matter, 0.454 acre inch of water was used to produce a bushel of wheat; 2.45 bushels of wheat were produced by each inch of soil water plus spring rainfall; and 0.87 bushel was grown by each inch of total water.

When acre yield of wheat was correlated with precipitation, it was found that the highest and most significant was with total water available followed by total rainfall. While the correlation of spring rainfall to yield was not high enough to be significant, it is recognized that without spring rain late-maturing stands in certain seasons may result in partial failure.

LITERATURE CITED

1. BRACKEN, A. F., and STEWART, GEORGE. A quarter century of dry-farm experiments at Nephi, Utah. Utah Agr. Exp. Sta. Bul. 222:1–44. 1930.
2. BRIGGS, H. J., and SHANTZ, H. L. Relative water requirement of plants. Jour. Agr. Res., 3:1–64. 1914.
3. BURR, W. W. The storage and use of soil moisture. Nebr., Agr. Exp. Sta. Res. Bul. 5:1–88. 1914.
4. CHILCOTT, E. C. The relations between crop yields and precipitation in the Great Plains Area. U. S. D. A. Misc. Cir. 81:1–94. 1927.
5. COLE, J. S., and MATHEWS, O. R. Use of water by spring wheat on the Great Plains. U. S. D. A. Bul. 1004:1–34. 1923.
6. FINNELL, H. H. The utilization of moisture on heavy soils of the southern Great Plains. Okla. Agr. Exp. Sta. Bul. 190:1–24. 1929.
7. FORTIER, SAMUEL. Evaporation losses in irrigation and water requirements of crops. U. S. D. A. Off. Exp. Sta. Bul. 177:1–64. 1907.
8. HARRIS, F. S., and JONES, J. W. Soil Moisture studies under dry farming. Utah Agr. Exp. Sta. Bul. 158:1–51. 1917.
9. HOPKINS, E. S. Water requirement of crops. Canada Exp. Farms, Div. Field Husb. Rpt., 1926:34–37. 1926.
10. WIDTSOE, J. A. Dry farming. (Pages 120–121.) New York: Macmillan Company. 1916.

A VERY RAPID AND EASY METHOD OF TESTING THE RELIABILITY OF AN AVERAGE AND A DISCUSSION OF THE NORMAL AND BINOMIAL METHODS[1]

S. R. MILES[2]

STATISTICAL methods, when used properly and with discrimination, are an invaluable tool in research, but statistical results are sometimes difficult to comprehend and the methods are often tedious to use. In a previous paper, the writer (2)[3] made a plea for the use of more easily understood methods of *stating* the reliability of the results of a research, and presented a table of odds to aid in attaining that objective. In the present paper a short method is presented for very rapidly and easily *determining* how much confidence can be placed in a particular average. In addition, the two common methods of determining the significance of an average are discussed and compared.

The tests of significance discussed in this paper may be used for a median, an ordinary mean (arithmetic average), a mean of differences secured by the pairing of values, a difference between two means when pairing is not done, or the more likely of two alternatives.

Although considerable knowledge of statistics is necessary for the reader to understand all the discussion which precedes the explanation of the use of the short method, most anyone can understand the little necessary to make accurate use of this method.

It is well to emphasize that in research certain things must be assumed and that if these assumptions are seriously in error, the conclusions may be wrong. This fact is too often forgotten. The first necessary assumption to be emphasized is that the sample with which the investigator works is truly representative of the larger population concerning which he wishes to generalize. Too much thought cannot be devoted to planning a research problem so that this assumption will be a fact. Tests of significance (reliability), too, are based on certain assumptions which will be discussed later.

THE NORMAL AND BINOMIAL METHODS

There are two commonly used methods of testing significance. The first, which we will call the *normal method*, is based on the normal distribution of individual values in an infinite population. The second, the *binomial method*, is based on the distributions of "successes" and "failures" when a "success" and a "failure" are equally likely. These distributions result from expanding the binomial $(\frac{1}{2} + \frac{1}{2})^n$ for any value of n.

Heretofore, the normal method has been used by calculating the root-mean-square deviation (standard deviation) and a t value and

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[3]Numbers in parenthesis refer to "Literature Cited," p. 31.

then finding the significance from a table. This procedure has been explained in detail by Student (4, 5), Fisher (1), the writer (2), and others. This particular procedure, which is much the most common for finding significance, is one way of applying the normal method and will hereafter be called the *usual normal method.* A second way of applying the normal method is one phase of the *short method* described in this paper.

The binomial method also is used to a considerable extent, but it could well be used a great deal more. Its use in agronomic work is largely due to Salmon (3), who showed how it can be applied in agronomy when values are paired. Pairing is not necessary, as will be shown in examples 4 and 5 of the use of the short method, and the binomial method may be used in all fields of research work.

The exactly correct binomial odds are obtained from the distribution which results from expanding the binomial $(\frac{1}{2} + \frac{1}{2})^n$. This binomial has been expanded by the writer for each value of n to 25. The results were used in preparing the tables and figures. Because of the difficulty of expanding the binomial, it is almost universal to obtain the *approximate* binomial odds by calculating the standard error and the deviation from the expected number of occurrences.

The best formula for computing the deviation from the expected in the case of the binomial method is

$$d = m - \tfrac{1}{2}n - \tfrac{1}{2}, \qquad (1)$$

when d is the deviation, m is the number of values which are larger (or smaller) than any selected value, and n is the total number of values in the sample. Also, n may be the number of trials and m the number of those trials which gave one of only two possible alternative results. The formula for the standard error is

$$S = \tfrac{1}{2}\sqrt{n}. \qquad (2)$$

To determine the significance of the deviation, also calculate t from the formula $t = d/S$. (3)

The significance of the deviation may be found by looking up the value of t in Miles' (2) table of odds, or in Student's (5) or Fisher's (1) tables of probability, using the column or row for an infinite number of degrees of freedom. If $t = 1.65$, the odds are 19 : 1, and if $t = 2.33$, the odds are 99 : 1, when a difference is being tested. If Fisher's table is used, the probability given at the head of the column should be divided by 2 to find the probability *against* the true value of the average being larger (or smaller) than the selected value. This is when a difference is being tested.

The procedure which has just been given may be called the *usual binomial method* and is one way of applying the binomial method. A second way of applying it is the second phase of the *short method* to be described.

In explaining the use of the usual binomial method, Salmon (3) worked with the probable error, whereas the standard error is somewhat preferable. More important, he did not include the last term of equation 1.

The need for the final term may be explained by the aid of Fig. 1. If a perfect coin is tossed, the head or the tail is equally likely to show.

Fig. 1 illustrates that if four perfect coins are tossed a great many times, we will expect to have on the average from 16 tosses no heads one time, one head four times, two heads six times, three heads four times, and four heads one time. Thus, because in 16 tosses three or four heads are expected five times, the odds are 11:5 (or 2.2:1) against securing three or more heads in one toss of four coins. Geometrically, the odds are found by dividing the polygon of Fig. 1 into two parts by the line AB which separates the rectangles representing the frequency of occurrence of three or more heads from the rest of the polygon. The ratio of the larger part of the polygon to the smaller part is the odds.

Equation 1 is used to find how far the division line should be from the center of the base of the polygon. For Fig. 1, m is 3 and n is 4 and the use of equation 1 gives ½ as the correct distance of the division line AB from the center. If the final term of equation 1 were omitted, the distance of the division line from the center would be indicated as 1.0 and the line would fall at C3. This division would give odds of 13:3 (or 4.3:1), which are too high. A similar argument for the final term would apply for all values of m and n.

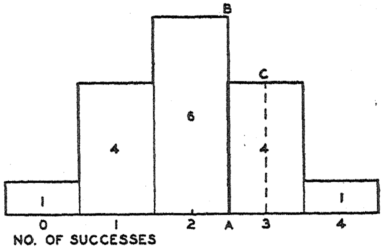

FIG. 1.—Polygon showing the relative expected frequency of occurrence of 0, 1, 2, 3, and 4 successes (or failures) in a large number of experiments of four trials each when a success or a failure is equally likely to occur at each trial. From $(\frac{1}{2}+\frac{1}{2})^n$.

Table 1 shows that the use of equation 1 gives a very satisfactory estimate of the true binomial odds, but that if the last term is omitted the estimate is seriously high.

TABLE 1.—*A comparison of the true binomial odds with estimates made by using two formulas.*

True odds	n*	Odds estimated by the two formulas	
		d = m — ½n — ½*	d = m — ½n*
19:1	7	17.8	40
	10	18.0	37
	25	18.6	29
	50	18.6	26
99:1	7	71	197
	10	75	185
	25	90	155
	50	94	138

*See the text for the meaning of the symbols and for the discussion of the equations.

NORMAL AND BINOMIAL METHODS COMPARED

Let us now compare the normal with the binomial method. The binomial method is based on only one assumption, namely, that the chances are equal for obtaining values on each of the two sides

of the true mean value. In contrast, when the normal method is used, three things are tacitly assumed. The first assumption is the same as for the binomial method; the second is that the values in the population sampled are distributed normally; and the third is that the estimate of the standard deviation made from the sample is correct for the population. As a rule, the assumption for the binomial method can be approximated closely in reality by carefully planning and executing the piece of research. Usually, however, considerable doubt must remain as to whether the last two assumptions for the normal method hold even reasonably well. An advantage of the binomial method is that it is based on only the one rather easily satisfied assumption.

The binomial method indicates lower significance (odds or probability) than the normal method when the distribution of the values *of the sample* is exactly normal. This is demonstrated as follows.

In the case of the usual normal method, let σ be the standard deviation of individual values, S the standard error of the mean[4], n the number of values in the sample, and d the deviation of the mean of the sample from any value which may be selected against which to test this mean. Since

$$S = \sigma/\sqrt{n}, \qquad (4)$$

therefore,

$$tS = t\sigma/\sqrt{n}. \qquad (5)$$

By definition—equation 3—

$$t = d/S,$$

therefore,

$$d = tS. \qquad (6)$$

Substituting in equation 5

$$d = t\sigma/\sqrt{n}. \qquad (7)$$

Next, decide on any normal odds, say 99: 1, for which the corresponding binomial odds are to be found for any value of n, say 100. In Miles' (2) table of odds in the column for an infinite number of degrees of freedom, find (odds of) 99, and to the left find the corresponding t value, which is 2.33. In equation 7 substitute 2.33 for t and 100 for n. Solving, gives $d = 0.233\sigma$.

Now if we select a value 0.233σ smaller (or larger) than the mean of the sample, the normal odds are 99: 1 that the true mean is larger (or smaller) than this selected value. A table of the probability integral shows that 59.2% of the values in a normal distribution lie to one side of a point 0.233σ from the mean, which is the selected point. For the problem at hand, this would be 59.2 values. Taking n as 100 and m as 59.2 and applying the usual binomial method, the binomial odds are found to be 23.6: 1. These correspond to normal odds of 99: 1. Reversing this procedure will give the normal odds corresponding to selected binomial odds.

Table 2 summarizes the results of repeated calculations for various odds and various values of n and shows that binomial odds are much lower than normal odds when the values *of the sample* are normally distributed. In practice, Student's odds should be used when n is 21

[4]The same symbol, S, is used both here in the discussion of the usual normal method and in the earlier discussion of the binomial method because in each case it represents the standard error appropriate to the method being discussed. The use of a single symbol makes possible the general formula $t = d/S$ which indicates that t is found by dividing any deviation (d) which it is desired to test for significance by the appropriate standard error, S.

or less. The table shows that the difference between Student's and binomial odds is not nearly so great as between normal and binomial odds. Also, in an empirical study[5] with over 90 sets of data from several fields of work, the writer found that in a great majority of the cases the usual normal method gave higher (normal or Student's) odds than the binomial method.

TABLE 2.—*A comparison of binomial odds with normal odds and with Student's odds when the values of the sample are distributed normally.*

Normal odds	Binomial odds for various values of n*						
	n = 5	6	10	20	35	100	1000
19:1.....	3.4	3.8	4.8	5.8	6.7	7.8	9.1
99:1.....	6.6	7.7	11.1	15.5	19.0	23.6	26.8
Binomial odds	**Normal and Student's odds for various values of n***						
	n = 5	6	10	20	35	100	1000
19:1.....	13,000 (103)†	1,650 (86)	317 (85)	145 (83)	99	71	50
99:1.....	‡	‡	55,000 (787)	3,500 (730)	2,150	1,000	660

*n is the number of values in the sample.
†Numbers in parenthesis are Student's odds from Miles' (2) table.
‡Bincmial odds as high as 99:1 are not possible with samples of 5 or 6.

Salmon (3) made two comparisons in which the two methods gave identical results. However, this was due to chance alone and indicates that the distributions of the sample values were not normal. In 18 of the 22 comparisons which he made, the binomial method indicated lower significance. Had he used equation 1, this method would have given lower significance in 20 of the 22 cases. This being true, the binomial odds are 16,512: 1 that the binomial method should give lower odds than the normal method.

Because the binomial curve is very nearly normal even for moderate values of n, many persons believe that the normal and binomial methods should give nearly the same odds. This should not be expected upon further thought. The two normal distributions are of entirely different things. For the normal method, it is frequencies of individual values, such as bushels, inches, etc., which are normally distributed, while, for the binomial method, it is frequencies of all possible combinations of the two alternatives. The combinations of the alternatives vary from all of the first and none of the second alternative to none of the first and all of the second. Another striking contrast is that for the normal method m and n are *areas* under the curve, whereas for the binomial they are *points* on the base line of the curve.

It can be shown that when the binomial method gives higher odds than the *usual normal method*, the distribution is so far from normal

[5]The writer is indebted to the following men for part of the data used in the empirical study: Dr. R. M. Caldwell, S. F. Thornton, J. F. Trost, M. O. Pence, and K. E. Beeson.

that the use of the latter is not valid. Thus, the binomial method is the better even when it gives the higher odds.

Another advantage of the binomial method is that it cannot give high odds with very small samples, whereas the *usual normal method* can give infinite odds even with samples of two. It is risky to place much confidence in very small samples.

The normal method will give odds greatly in error for badly skewed distributions. The binomial method, however, is properly used even in such cases.

The normal method always tests the mean, whereas the binomial method always tests the median. (The median is a value larger than half the values and smaller than the other half.) In symmetrical distributions, the median and the mean coincide and in such cases the binomial method tests both. Throughout this paper reference is made to tests of the mean, but when the mean and the median do not coincide it should be remembered that the binomial method tests the latter.

The binomial method cannot lead to one kind of serious error to which the *usual* normal method may lead if used blindly. The latter may indicate that a certain mean is significant even when that constant does not represent the data at all well because the sample is very badly skewed. In several of the 90 cases which were used in the empirical study previously mentioned, it was found that the mean represented the data very poorly because it had a sign opposite that of the majority of the values. The *usual* normal method does not reveal such a fact, but the binomial or the short method will do so when correctly used. In one case the *usual* normal method gave the significant odds of 34:1 that the true mean had a negative sign, although a majority of the signs in the sample were positive. The binomial odds were 2:1 that most of the signs were also positive in the population represented by the sample. Neither the usual binomial method nor the short method for either normal or binomial odds can lead to such an error in judging the significance of a mean as resulted from the use of the *usual* normal method in this case.

Faulty technic and errors of various kinds produce data containing erroneous values. Such values have no effect upon the odds secured by the binomial method unless one or more values are changed from one side to the other of the value selected to be tested as the true mean. With the *usual* normal method, on the other hand, every value is used in computing both the mean and the standard deviation, and, as a consequence, erroneous values are almost certain to affect the odds.

The *usual binomial method* is much easier to use and much more rapid because it requires less calculation than the *usual normal method*. In fact, the calculations for the former can often be performed mentally with sufficient accuracy when the odds are definitely significant. By convention, odds of 19:1 are generally considered significant. Therefore, when a difference is being tested, a t value (see equation 3) greater than 1.65 may be taken to indicate significance.

The one disadvantage of the binomial method is that it gives odds which are too low or unnecessarily conservative when all three assumptions hold on which the normal method is based.

KIND OF ODDS TO USE

The comparison of the two methods leads to the question as to which is correct. The answer is that each is correct for the assumptions on which it is based. The comparison shows that the binomial odds are safe. This is because any well-planned and well-conducted research should closely meet the one assumption for the binomial method. The writer has been unable to think of any possible data from careful research to which this method could not be applied with confidence if the facts in the italicized paragraph above are kept in mind.

On the other hand, the normal method not infrequently gives results seriously in error because all three conditions on which it is predicated do not obtain. It is not safe, therefore, to use this method blindly, as is so commonly done.

What then is the practical thing to do in deciding which kind of odds to use? The binomial odds should be found first because they are safe and because they are easier to find when the table or graphs for the short method are not at hand. If the binomial odds are significant, there is no object in going farther. If these odds are low, the normal odds may then be found if the worker is anxious to show significance. Then if the normal odds are significant, the shape of the distribution of the values in the sample should be investigated. Generally, confidence should be placed in the normal odds only if the distribution is nearly normal. Occasionally, as in example 5 below, conditions are such that an experienced person may confidently use normal odds without testing the distribution.

It is well to state the kind of odds reported, and *the use of normal odds should be justified when their use is necessary to show significance.*

THE SHORT METHOD

The short method can be used to find either normal or binomial odds, and it is much faster and easier than either usual method. This method gives binomial odds which are always correct and normal odds which are the same or approximately the same as are given by the usual normal method when the distribution of the values *in the sample* is normal or approximately so.

Briefly, the short method is used by counting the total number of values in the sample and also the number larger (or smaller) than any selected value. Table 3 or Fig. 2 or 3 is then used to find the odds that the true value of the average being tested is larger (or smaller) than the selected value.

Table 3 gives the correct binomial odds for values of n from 2 to 25. In Figs. 2 and 3 curves are used to indicate the odds. Fig. 2 is used when n is 30 or less, while Fig. 3 is used when n exceeds 30. For points on curve A, the *normal* odds are 19 : 1; for curve B the *binomial* odds are 19 : 1 and the *normal* odds are high; for curve C the *binomial* odds are 99 : 1 and the *normal* odds are very high. The lower half of Table 2, which shows the normal odds corresponding to binomial odds of 19 : 1 and 99 : 1 for various values of n, shows more definitely the normal odds represented by various points on curves B and C. Most persons will do well to be conservatively safe by using only curves B and C for odds of 19 : 1 and 99 : 1, respectively.

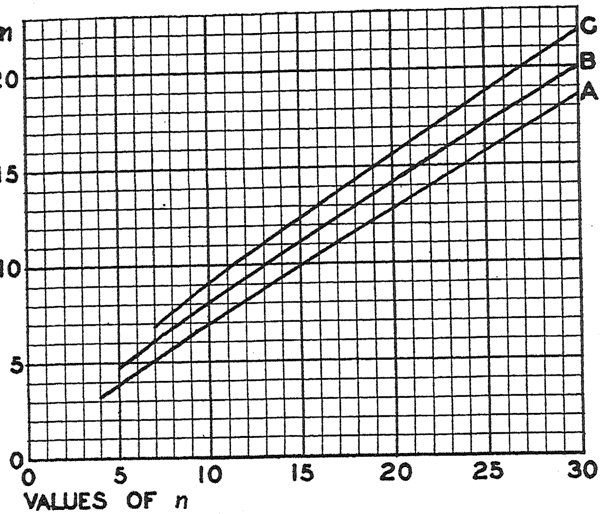

FIG. 2.—Curves of binomial and normal odds for values of n to 30. n, number of values in the sample or number of trials; m, number of values larger (or smaller) than any selected value or number of successes (or failures).

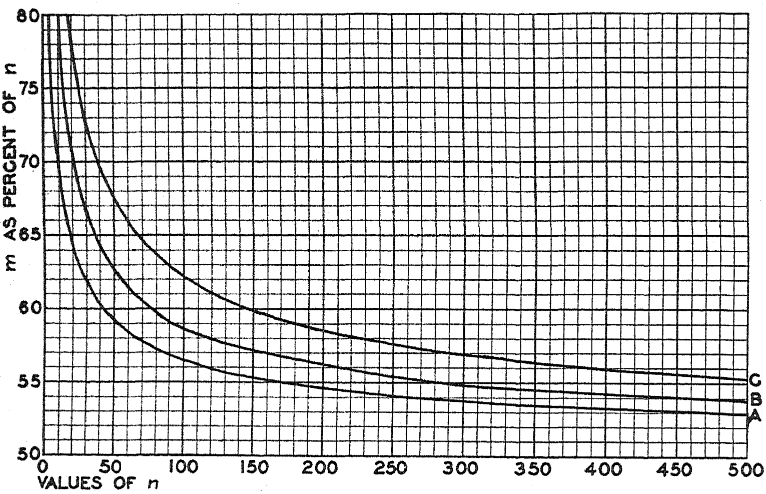

FIG. 3.—Curves of binomial and normal odds for values of n to 500. n, number of values in the sample or number of trials; m, number of values larger (or smaller) than any selected value or number of successes (or failures).

The odds shown by Figs. 2 and 3.

Curve	Kind of odds	
	Binomial	Normal
A.	Low	19:1
B.	19:1	High
C.	99:1	Very high

TABLE 3.—*Odds against the occurrence of m or more like results, purely by chance, in n trials, from two alternatives which are equally likely to occur, for values of n from 2 to 25.**

m	n=2	3	4	5	6	7	8	9	10	11	12	13
2	3.0	1.0	—	—	—	—	—	—	—	—	—	—
3	—	7.0	2.2	1.0	—	—	—	—	—	—	—	—
4	—	—	15.0	4.3	1.9	1.0	—	—	—	—	—	—
5	—	—	—	31.0	8.1	3.4	1.7	1.0	—	—	—	—
6	—	—	—	—	63.0	15.0	5.9	2.9	1.6	1.0	—	—
7	—	—	—	—	—	127	27.4	10.1	4.8	2.6	1.6	1.0
8	—	—	—	—	—	—	255	50.2	17.3	7.8	4.1	2.4
9	—	—	—	—	—	—	—	511	92.2	29.6	12.7	6.5
10	—	—	—	—	—	—	—	—	1,023	170	50.8	20.7
11	—	—	—	—	—	—	—	—	—	2,047	314	88.0
12	—	—	—	—	—	—	—	—	—	—	4,095	584
13	—	—	—	—	—	—	—	—	—	—	—	8,191

m	n = 14	15	16	17	18	19	20
8	1.5	1.0	—	—	—	—	—
9	3.7	2.3	1.5	1.0	—	—	—
10	10.1	5.6	3.4	2.2	1.4	1.0	—
11	33.8	15.9	8.5	5.0	3.1	2.1	1.4
12	153	55.9	25.0	12.9	7.4	4.6	3.0
13	1,091	270	93.0	39.8	19.8	11.0	6.6
14	16,383	2,047	477	156	63.7	30.5	16.3
15	—	32,767	3,854	850	264	103	47.3
16	—	—	65,535	7,281	1,523	451	168
17	—	—	—	131,071	13,796	2,744	775
18	—	—	—	—	262,143	26,213	4,969
19	—	—	—	—	—	524,287	49,931
20	—	—	—	—	—	—	1,048,575

m	n = 21	22	23	24	25
11	1.0	—	—	—	—
12	2.0	1.4	1.0	—	—
13	4.2	2.8	1.9	1.4	1.0
14	9.5	6.0	3.9	2.7	1.9
15	24.5	13.9	8.5	5.5	3.7
16	74.2	37.1	20.5	12.2	7.7
17	277	117	56.7	30.3	17.5
18	1,342	459	187	87.3	45.2
19	9,038	2,337	768	302	135
20	95,324	16,512	4,095	1,292	490
21	2,097,151	182,360	30,283	7,220	2,196
22	—	4,194,303	349,524	55,700	12,777
23	—	—	8,388,607	671,000	102,927
24	—	—	—	16,777,215	1,290,554
25	—	—	—	—	33,554,431

*From the binomial $(\frac{1}{2}+\frac{1}{2})^n$.

Some examples of the use of the short method follow. The first three are different kinds of tests when pairing has been done.

Example 1.—E and F were compared in 25 pairs. In 20 pairs the value of E exceeded that of F. In Fig. 2 it is found that the point mn, the intersection of vertical line 25 (for n) and horizontal line 20 (for m), is above curve C. The binomial odds are therefore greater than 99: 1 that the mean of E really exceeds that of F. Table 3, in the column for $n = 25$ and on the line for $m = 20$, gives the exact binomial odds as 490: 1. The values of E and F may have been expressed as bushels, feet, cubic inches, or any other unit of measure.

Example 2.—In the sample of example 1, 18 values of E exceeded the corresponding values of F by more than 2.5. Because the point mn for $n = 25$ and $m = 18$ is between curves B and C, the binomial odds are between 19: 1 and 99: 1 that the true mean of E exceeds that of F by at least 2.5. Table 3 gives the exact binomial odds as 45.2: 1.

Example 3.—G and H were compared in 30 pairs. G exceeded H 27 times. For how large a difference are the binomial odds 19: 1? The (vertical) line for $n = 30$ intersects curve B of Fig. 2 on the (horizontal) line for $m = 20$. Therefore, m must be 20 for odds of 19: 1. Arrange the amounts by which G exceeded H in order of size. Count from the largest to the 20th in size, which we will suppose is 4.0. Then the binomial odds are 19: 1 that G really exceeds H by at least 4.0.

Ties are rather common when values are paired. In some cases it is proper to divide the ties equally between the two alternative classes, but in other cases the ties must be omitted. It is suggested that ties always be omitted in counting both m and n when the test being made is that the true mean difference is greater (or less) than zero, which was the test made in example 1. When ties are omitted, the odds found are the odds that *when there is a difference* the true mean difference is greater (or less) than zero. For tests such as were made in examples 2 and 3, the ties should be included.

When pairing is not logical, the test of the significance of a difference between two means is made somewhat differently. It can be shown that when two distributions are about normal, when both means have the same standard error, and when the normal odds are exactly 99: 1 that the *true* value of each mean differs from the *estimated* value of the other mean, then the normal odds are exactly 19: 1 that the *true* value of the larger *estimated* mean is larger than the *true* value of the other mean. Therefore, if both points mn found in testing each mean against the other are on or above curve B, the normal odds are very likely at least 19: 1 that the two means are really different. Also, if one point mn is only slightly below curve B and the other point mn is well above curve B, the normal odds are very likely at least 19: 1 that the true means are different. It is probably correct to use the same procedure for binomial odds by using curve C instead of B, though this has not been proved. The next example illustrates the use of the short method when pairing is not possible. This test should be made only if the values of n in the two samples are not greatly different.

Example 4.—A sample of 28 men from race P had a mean height of 60 inches and a sample of 21 men from race Q had a mean height of 65 inches. Nineteen men of race P were shorter than 65 inches and 15 men of race Q were taller than 60 inches. In Fig. 2, point mn for P, with $n = 28$ and $m = 19$, is slightly above curve B. Point mn for Q, with $n = 21$ and $m = 15$, is also above curve B. Therefore, the normal odds are very probably at least 19: 1 that the men of race P really average shorter than the men of race Q.

The next example tests an ordinary mean to see whether its true value is smaller than a selected value.

Example 5.—Suppose that extensive research has shown that the true average height of men of race J is 66 inches. In a random sample of 400 men of race K, 216 were shorter than 66 inches. What are the odds that the true mean height of men of race K is less than that for men of race J? Fig. 3 must be used because the sample is larger than 30. For using Fig. 3, m must be expressed as a percent of n, so we calculate to find that 216 is 54% of 400. The point mn, for $n = 400$ and $m = 54$, is between curves A and B. The binomial odds are less than 19: 1, but the normal odds are considerably greater than 19: 1 that the men of race K really average shorter than the men of race J. The use of normal odds in this case is very probably justified because heights are known to be normally distributed and because the sample is large.

Fig. 3 shows that as the size of the sample increases there is a decrease in the percentage of the values which must fall on one side of any selected value in order to show a significant difference between the selected value and the true value of the mean which has been estimated. The decrease is very rapid for small samples. This shows why a small increase in the size of a small sample adds greatly to the confidence which can be placed in an average.

CONCLUSION

With the short method available, there is no virtue in using the longer, more tedious methods, and many averages can be tested for reliability which would not be tested by the longer methods.

LITERATURE CITED

1. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh and London: Oliver and Boyd. Ed. 4 (1932), or earlier editions.
2. MILES, S. R. A new table of odds based on Student's table of probability. Jour. Amer. Soc. Agron., 26:341–346. 1934.
3. SALMON, S. C. The point binomial formula for evaluating agronomic experiments. Jour. Amer. Soc. Agron., 22:77–81. 1930.
4. STUDENT. The probable error of a mean. Biometrika, 6:1–21. 1908.
5. ———. New tables for testing the significance of observations. Metron, 5:105–118. 1925.

THE NODULATION AND OTHER ADAPTATIONS OF CERTAIN SUMMER LEGUMES[1]

J. F. DUGGAR[2]

THE chief object in conducting the field experiments here reported was to compare the less-known summer legumes with the kinds in common use with respect to nodulation, earliness, productiveness, palatability, and injury by common pests. The plants were grown at Auburn in 1928, 1929, and 1930 in rows 3 feet apart on upland Norfolk soil. Usually two or three plantings were made each season.

ROOT NODULE FORMATION AND RELATIVE EARLINESS OF SUMMER LEGUMES

It seemed especially desirable to learn which species would form nodules spontaneously on sandy acid soils, and which kinds, therefore, might here be independent of artificial inoculation, which was uniformly omitted. Periodic examinations were made of representative samples of the young seedlings to determine the percentage of plants supplied with one nodule or more. With some species the examinations were continued for several months and counts made on these to ascertain the average number of root nodules per plant.

Table 1 summarizes the data on nodulation and earliness, the latter as measured by number of days from emergence to the beginning of blooming.

On these sandy, acid soils there was complete or nearly entire failure to form any root nodules by *Dalea*, *Daubentonia* sp., *Se bania*, wild sensitive vine (*Acuan*), young seedlings of black locust, wild perennial bean (*Dolicholus minimus*), navy bean, tepary bean, and bush lima bean. This indicates the need for artificially inoculating the seed of the three last-mentioned economic beans when grown for the first time. Yet adsuki, moth, "poultry," and rice beans, which belong with them in the same genus, *Phaseolus*, were able to develop root nodules in abundance without artificial inoculation.

This difference in nodulation between species within the same genus of beans is practically paralleled by two other cases elsewhere reported by the author. These showed (1) marked obstacles in Korean lespedeza plants (*L. stipulacea*) to cross inoculation with *L. striata*,[3] and (2) notable differences in the spontaneous nodulation of two types of peanut,[4] Runner and Spanish, both belonging to the same species, *Arachis hypogœa*.

The above facts as to *Phaseolus*, *Lespedeza*, and *Arachis*, together with nodulation studies of varieties of soybeans by other investigators, suggest that the usually accepted list of strains of bacteria

[1]Contribution from the Department of Special Investigations, Alabama Agriculture Experiment Station, Auburn, Ala. Received for publication November 9, 1934.

[2]Research Professor.

[3]DUGGAR, J. F. Differences between Korean and other annual lespedezas in root nodule formation. Jour. Amer. Soc. Agron., 26:917–919. 1934.

[4]DUGGAR, J. F. Nodulation of peanut plants as affected by variety, shelling of seed, and disinfection of seed. Unpublished paper.

capable of functioning in symbiosis with the legumes may need to be considerably extended.

With most species of summer legumes, delays in the date of planting and emergence hastened maturity, that is, shortened the interval between emergence and initiation of blooming.

On the basis of average figures following early, medium, and late planting, we may regard as *late* in blooming the common speckled velvet bean, "poultry" bean, mung bean, beggarweed, *Crotalaria*,

TABLE I.—*Days after emergence for at least 85% of seedlings to develop one nodule or more and for the beginning of blooming; plantings made in May, June, and July, 1928, 1929, and 1930.*

Plant	Usual no. days to early generalized nodulation	Relative no. nodules per plant	Average no. days to beginning of blooming
Prompt in Attaining Generalized Nodulation			
Cowpea, Brabham (*Vigna sinensis*)	5–7	Many	55
Soybean, Laredo (*Soja max*)	8–13	Many	48
Lespedeza, common* (*L. striata*)	8–14	Many	109
Lespedeza, Kobe* (*L. striata*)	8–14	Many	103
Lespedeza, Tenn. 76* (*L. striata*)	8–14	Many	107
Velvet bean, Early Speckled (*Stizolobium deeringianum*)	10–14	Medium	65
Velvet bean, Arlington	——	——	47
Velvet bean, Osceola	——	——	50
Velvet bean, Yokohama	——	——	54
Crotalaria striata	5–7	Many	62
Crotalaria sericea	5–7	——	73
Adsuki bean (*Phaseolus angularis or radiatus*)	7–13	Medium	45
Moth bean (*P. aconitifolius*)	9–10	——	——
"Poultry" bean (*P. calcaratus*), naturalized	4–13	Many	74
Rice bean (*P. calcaratus*)	7–13	Medium	42
Urd bean (*P. mungo*)	4–13	Medium	40
Wild annual bean, (*Strophostyles helvola*)	8–11	Many	44
Mimosa (*Albizzia julibrissin*)	13	Many	No bloom
Medium in Nodulating Time			
Beggarweed, Fla. (*Desmodium purpureum*)	19–24	Medium	62
Hyacinth bean (*Dolichos lablab*)	9–20	Medium	50
Mung bean, (*Phaseolus aureus*)	9–19	Few—medium	64
Runner peanut (*Arachis hypogæa*)	——	Many	28
Wild sensitive plant (*Chamaecrista nictitans*)	10–16	Many	——
Very Late in Nodulating			
Calopogonium mucuniodes	——	Few	——
Guar (*Cyamopsis tetragonoloba*)	31–48	Medium	50
Kudzu (*Pueraria thunbergiana*), first year from seed	37	Medium	No bloom
Lespedeza, Korean* (*L. stipulacea*)	30–70	Very few	71
Spanish peanut (*Arachis hypogæa*)	——	Few	23
Sword bean (*Canavalia ensiformis*)	19–40	Few	46

*Lespedezas planted early in April.

TABLE 1.—*Concluded.*

Plant	Usual no. days to early generalized nodulation	Relative no. nodules per plant	Average no. days to beginning of blooming
Not Forming Nodules			
Bush lima bean (*Phaseolus luanatus*)...	——	None	38
Navy bean (*P. vulgaris*)............	——	None	44
Tepary bean (*P. acutifolius*).........	——	None	36
Wild perennial bean (*Dolicholus minimus*).........................	——	None	—
Black locust (*Robinia pseudacacia*)....	——	None	No bloom
Dalea (*D. alopecuroides*)............	——	None	51
Daubentonia sp...................	——	None	101
Sesbania macrocarpa...............	——	None	73
S. vesicaria......................	——	None	77
Acuan sp., first year from seed.......	——	None	No bloom

Sesbania, and the three native or naturalized perennial legumes, *Daubentonia*, sensitive vine (*Acuan*), and the small wild bean, (*Dolicholus minimus*).

Medium or intermediate in promptness of blooming were Yokohama, Osceola, and Arlington velvet beans, Brabham cowpea, Laredo soybean, hyacinth bean, guar, and sword bean. Early blooming plants included Spanish and Runner peanuts, rice bean, adsuki bean, urd bean, the three table beans, navy, tepary, and bush lima beans, and the wild annual legume from Ohio, *Strophostyles helvola*.

RELATIVE PRODUCTIVENESS

Observations and measurements of plants as grown in rows during each of three seasons justified the following general classification of the summer legumes tested on the basis of luxuriance of growth:

Large production of green material, usually coarse, velvet bean, kudzu, sword bean, *Crotalaria striata*, *C. sericea*, *Sesbania macrocarpa*, *S. vesicaria*, and *Daubentonia*.

Medium production of green material, usually of good quality, soybean (Laredo variety), cowpea (Brabham variety), "poultry" bean, rice bean, moth bean, hyacinth bean (rather coarse), mung bean (usually coarse), guar (rather coarse), beggar weed (sometimes coarse), wild sensitive plant, and Runner peanut.

Smaller production of green material, urd bean, adsuki bean, *Strophostyles helvola*, *Dolicholus minimus*, tepary bean (for seed), navy bean (for seed), bush lima bean (for seed), Spanish peanut, Kobe, Tennessee 76, Common, and Korean lespedezas, Acuan, and Dalea.

RELATIVE PALATABILITY OF CERTAIN SUMMER LEGUMES

Those species that showed most luxuriant growth were cut in October, 1928, in the rather late stages regarded as suitable for silage. The freshly cut forage was offered simultaneously to a herd of beef cattle of varied ages that was running on a good pasture. Table 2 shows the results of this test.

TABLE 2.—*Relative palatability for cattle of green forage of certain summer legumes.*

Plant	Stage of growth	Readiness with which eaten	Refused parts
Beggarweed	Early-pod stage, coarse stems	Ravenously and first	Only coarsest stems
"Poultry" bean	Filled green pods, good hay stage	Completely	None
Cowpea	⅔ pods colored	Readily	Only coarsest stems
Velvet bean	Late blooms and unfilled pods	Readily	Only largest stems
Hyacinth bean	Late-blooms and unfilled pods	Leaves only	All stems and most green pods
Mung bean	Most pods colored, leaves mildewed	Incompletely	Most stems and ripe pods
Crotalaria sericea	Late full bloom	Refused	All leaves and stems
Sword bean	Late bloom, flat, green pods	Refused	All leaves, pods, and stems
Guar	Late bloom, leafy	Refused	All leaves and stems

Beggarweed and "poultry" bean ranked first in palatability, followed in turn by the cowpea and velvet bean. The kinds that were entirely refused in the green condition were *Crotalaria* sp., sword bean, and guar.

Similar samples were harvested from the crop of 1930, run through a silage cutter, packed into burlap sacks, and imbedded in a silo while it was being filled with sorghum. This silo was opened after about 15 months and the cut silage of the legumes was separately offered to dairy cows and young heifers. The samples were offered in 33 pairs.

In six trials silage from soybean and velvet bean was eaten equally well and led all others in palatability. Next followed silage from mung bean and from guar. Even that from sword bean and *Crotalaria* sp. was eaten fairly well by most animals when preserved in close contact with sorghum silage.

RELATIVE INJURY BY MEXICAN BEAN BEETLE, NEMATODES, AND PLANT DISEASES

The summer legumes tested in these experiments differed widely in the extent to which their leaves were injured by the Mexican bean beetle, (*Epilachna corrupta*). Those that were most severely injured in seasons when this pest was rather abundant were navy bean, bush lima bean, and tepary bean. Florida beggar weed sometimes suffered material injury from this insect.

The plants that proved to be entirely or practically exempt from the attacks of the Mexican bean beetle were two species of *Crotalaria*, two species of *Sesbania*, guar, sword bean, *Dolicholus minimus*, *Chamaecrista nictitans*, *Acuan*, *Daubentonia*, black locust, mimosa, four annual *Lespedezas*, and Spanish and Runner peanut, and, in a single test, moth bean.

The kinds attacked but never materially injured by the Mexican bean beetle in these experiments included cowpea, soybean, velvet bean, kudzu, "poultry" bean, mung, rice, urd, and adsuki beans, hyacinth bean, and *Strophostyles helvola*.

The plants on which no root galls caused by the common nematode (*Heterodera radicicola*) could be found in any year were beggar weed, Laredo soybean, Brabham cowpea, peanut, *Crotalaria striata*, guar, *Dolicholus minimus*, and wild sensitive plant. Among the plants on which nematode galls were especially numerous were *Sesbania macrocarpa*, *S. vesicaria*, hyacinth bean, *Phaseolus calcaratus*, and other beans from India.

Especially susceptible to injury by leaf diseases, including a mildew, were mung, urd, and adsuki beans; less susceptible was the acclimatized variety of *Phaseolus calcaratus* which was obtained under the commercial name of "poultry" bean. The leaves of Brabham cowpea were sometimes attacked by mildew.

Guar was notably susceptible on acid soils to injury by a soil rootrot (*Sclerotium sp.*). This disease also attacked Korean Lespedeza.

PROMISING KINDS

Kobe and Tennessee 76 lespedezas were found decidedly more luxuriant in growth than the annual lespedeza that is commonly grown; otherwise these experiments afforded no evidence of decided superiority possessed by any little-grown summer legume over the cowpea, soybean, and velvet bean for the production of forage under usual conditions.

However, some of the less widely known summer legumes seemed to offer sufficient promise in one or more qualities to justify further experimentation as to their suitability for special conditions. This tentative list includes beggar weed, moth bean, the acclimatized variety of *Phaseolus calcaratus*, tepary bean, and possibly *Strophostyles helvola*.

The *Crotalarias*, *Sesbania macrocarpa*, and sword bean, all notable for their large production of coarse material, are of probable value under special conditions for soil improvement and possibly for other uses.

SUMMARY

Data are summarized for a number of summer legumes on promptness with which each became inoculated and on their relative earliness, luxuriance of growth, palatability, and extent of injury by Mexican bean beetle and nematodes.

Those found especially prompt in the spontaneous development of root nodules included Brabham cowpea, Laredo soybean, velvet bean, Common, Tennessee 76, and Kobe lespedezas, five species of *Phaseolus* from India, *P. calcaratus*, *Strophostyles helvola*, *Crotalaria striata*, and *C. sericea*.

Somewhat slower in nodulation but also naturally well supplied ultimately with root tubercles were Runner peanut, beggar weed, hyacinth bean (*Dolichos lablab*), mung bean, and wild sensitive plant (*Chamaecrista nictitans*).

There was complete or nearly complete failure to form nodules spontaneously by navy bean, tepary bean, bush lima bean, *Dolicholus minimus*, *Acuan*, *Daubentonia*, *Dalea*, *Sesbania macrocarpa*, and *S. vesicaria*. The apparent anomalies involved in the contrasting nodu-

lation behavior of various species of *Phaseolus*, of two species of annual lespedeza, and of the Spanish and Runner varieties of peanuts suggest the probable need for extending the usually accepted list of races of bacteria symbiotic with leguminous plants.

The list of legumes making most luxuriant growth included velvet bean, kudzu, *Crotalaria striata*, *C. sericea*, and *Sesbania macrocarpa*.

Silage from *Crotalaria sericea*, guar, and sword bean, all surrounded for months in the silo by sorghum silage, was eaten with fair relish by cattle, but the fresh forage from each of these three species was wholly rejected.

Uninjured by common pests were the following: (1) By the Mexican bean beetle, *Crotalaria*, *Sesbania*, guar, sword bean, *Dolicholus minimus*, *Chamaecrista nictitans*, annual lespedezas, and peanut; (2) by nematodes, beggar weed, Brabham cowpea, Laredo soybean, *Crotalaria striata*, guar, and *Dolicholus minimus*. Guar and Korean lespedeza were especially susceptible to a soil rootrot. Mung and urd beans were among the species most severely injured by leaf diseases.

Only Kobe and Tennessee 76 lespedezas proved to be superior on the whole to comparable legumes now in general use. However, sufficiently promising for further experimentation seemed *Crotalaria*, *Sesbania macrocarpa*, beggar weed, the late acclimatized form of *Phaseolus calcaratus*, moth bean, and possibly *Strophostyles helvola*.

INFLUENCE OF CORN SMUT AND HAIL DAMAGE ON THE YIELD OF CERTAIN FIRST-GENERATION HYBRIDS BETWEEN SYNTHETIC VARIETIES[1]

R. J. GARBER AND M. M. HOOVER[2]

IN an earlier paper (2)[3] some evidence was presented which indicated that yield in corn may not be reduced because of smut (*Ustilago zeæ*) to the extent that is commonly supposed. In this earlier work both with selfed lines and with first-generation crosses between them, the only significant decrease in yield was that attributable to the greater incidence of barrenness among smutted plants. On the other hand, somewhat similar studies conducted in Minnesota (3, 4) and in Ohio (5), with few exceptions, showed marked decreases in yield caused by smut. The more vigorous selfed lines and first-generation crosses as reported by Kyle (6) of the U. S. Dept. of Agriculture showed the greater number of smut boils. The purpose of this paper is to present additional data relative to the influence of smut on yield, and incidentally, to present some data which show the extent to which yields may be lowered because of hail damage.

MATERIAL AND METHODS

During the seasons of 1932 and 1933 certain first-generation hybrids between synthetic varieties were grown on the agronomy farm near Morgantown, W. Va. Each synthetic variety was made up from three to six selfed lines isolated from various varieties. The relative time of maturity and color of seed are indicated by the names of the synthetics as follows: Early Yellow, Medium Yellow, Medium White, Late Yellow, and Late White. The first generation crosses between Early Yellow and each of the others, as well as crosses between Medium White and Medium Yellow, were classified into Group I, and all other crosses into Group II on the basis of relative maturity.

Each first-generation hybrid was grown in single-row plats repeated six times in randomized blocks. The rows were approximately 136 feet long and 3½ feet apart, with the hills spaced 15 inches along the row. Two and three seeds were planted per hill and later the stand was thinned to a single stalk. The parental synthetic varieties and certain commercial varieties, namely, Lancaster Sure Crop, Reid's Yellow Dent, and Woodburn White Dent, were also included in the planting.

When the corn was about knee high an application of horse manure, which a few days previously had been treated with smut spores, was made. Two later similar applications were made at intervals of 10 days.

Detailed notes on smut infection as to size of boil and place of occurrence on each individual host plant were made twice during the growing season—late in August and about the middle of September. Additional notes on ear infection were made when the corn was harvested. The location of a smut boil was indicated by an appropriate descriptive note. For example, "neck" meant that the host carried

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[3]Reference by number is to "Literature Cited," p. 45.

a boil just below the tassel, and "above ear" that a boil appeared at the first or second node above the ear.

Yields both of grain and forage were determined after the ears or the entire plants were dried in a drying house to a moisture content of approximately 1%. Grain yields (shelled corn) were obtained from ears fully matured and forage yields from entire plants considered at the proper stage of maturity for ensiling. The yields of paired smutted and smut-free plants were in all cases from adjacent hills in the same row. The experiments in 1932 and 1933 were identical except that in the latter year grain yields were determined on some of the paired plants and forage yields on the remainder of the paired plants.

SMUT AND YIELDS

In Table 1 are shown the average differences between the yields of paired plants (smutted and smut-free) and their respective significance according to Fisher's (1) modification of Student's table. The four comparisons possible (column 5) with "tassel"-infected plants show three of them to be in favor of the smutted and one in favor of the smut-free plants, but none of the differences is significant. Four comparisons are also available involving "neck" infections and in this case one of the average differences between yields is significant, namely, the one obtained among the group 1 crosses grown in 1932. An average difference of 28.3 grams (P = .018) of shelled corn in favor of the smut-free plants was obtained. Similarly, among the paired "base"-infected and smut-free plants one significant average difference was found and here again it was with the earlier maturing or group 1 crosses. The average difference in this case is 31 grams in favor of the smut-free plants. The P value is .023 computed from 18 differences, a rather small number. Of the 12 average differences (column 5) listed in Table 1, 5 are in favor of the smutted plants and 7 in favor of the smut-free plants, although only two of these differences have any statistical significance (column 6).

TABLE 1.—*The average difference and its significance of yield in grams of grain per plant between smutted and smut-free corn plants in first generation crosses between synthetic varieties grown on the agronomy farm near Morgantown, W. Va.*

Group* of F_1 crosses	Year grown	Place of smut infection	Number of pairs	Average difference in yield, grams	Significance of difference P
(1)	(2)	(3)	(4)	(5)	(6)
I.	1932	Tassel	38	6.1	0.5
II.	1932	Tassel	10	— 2.2†	0.9
I.	1932	Neck	39	28.3	0.018
II.	1932	Neck	12	—13.0	0.6
I.	1932	Base	100	10.1	0.1
II.	1932	Base	63	8.1	0.4
I.	1933	Tassel	63	— 4.6	0.6
II.	1933	Tassel	17	—14.8	0.5
I.	1933	Neck	101	19.7	0.4
II.	1933	Neck	34	19.4	0.1
I.	1933	Base	18	31.0	0.023
II.	1933	Base	13	—10.6	0.5

*Group I earlier maturing; group II later maturing.
†Negative signs indicate difference is in favor of smutted plants.

In Table 2 are presented the average differences in yields of forage between paired plants grown in 1933. The differences are all small (column 4) and none of them is significant (column 5).

TABLE 2.—*The average difference and its significance between total dry weight of smutted and smut-free corn plants cut at the proper time for ensiling in first generation crosses between synthetic varieties grown on the agronomy farm near Morgantown, W. Va., in 1933.*

Group* of F_1 crosses	Place of smut infection	Number of pairs	Average difference in total weight, grams	Significance of difference P
(1)	(2)	(3)	(4)	(5)
I	Tassel	82	1.4	0.9
II	Tassel	34	1.6	0.9
I	Neck	117	13.7	0.1
II	Neck	47	—12.1	0.5
I	Base	37	1.6	0.9
II	Base	25	2.0	0.9

*Group I earlier maturing; group II later maturing.

If yield in corn is lowered by the presence of smut, one would naturally expect, as has been pointed out (4), that the size of the smut boil would be correlated with the extent of the decrease in yield. In this investigation smut boils of the approximate size of a hen's egg or larger were designated as size 4.

In Table 3 the average differences in yields between paired plants, one of which showed a size 4 smut boil and the other no smut, are shown. For the purpose of obtaining as large a number of comparisons as possible "below ear" and "base" (column 3) infections were considered together. No significant differences in yield (columns 5, 6, and 7) were found here. Among the plants grown in 1933 and infected

TABLE 3.—*The average difference and its significance between yield of smutted and smut-free corn plants where all smutted plants had at least a size 4 smut boil.**

Group of F_1 crosses†	Year grown	Place of smut infection	Number of paired plants	Ave. difference in yield, grams		Significance of difference P
				Grain	Forage	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
I	1932	Below ear and base	38	6.6		0.5
II	1932	Below ear and base	36	—1.0		0.9
I	1933	Below ear and base	20		20.2	0.3
II	1933	Below ear and base	12		—7.8	0.9
I	1933	Neck	48	25.5		0.018
II	1933	Neck	27	19.1		0.2
I	1933	Neck	72		25.8	0.017
II	1933	Neck	27		—4.1	0.8

*Smut boils as large as a hen's egg or larger.
†Group I earlier maturing; group II later maturing.

in the "neck" two significant average differences appeared. In the Group 1 crosses 48 smut-free plants yielded on the average 25.5 grams (column 5) more shelled corn than 48 similar plants with size 4 smut boils. An average difference of 25.8 grams in yield of forage (column 6) was obtained between 72 similar pairs of plants in the same crosses. These average differences are both significant and the fact that they are so nearly alike suggests that the reduction in yield of forage may be attributed primarily to the reduction in yield of grain. Of the eight comparisons shown in Table 3 only two gave average differences that were significant (column 7) and these significant differences, as in Tables 1 and 2, were obtained among group 1, the earlier maturing, first-generation crosses.

SMUT AND BARRENNESS

In this investigation, as in the one reported earlier (2), the presence of smut was associated with greater barrenness as shown in Table 4. The percentage of barren stalks in 1933 among the smut-free plants (column 4) in commercial varieties was 8.33; in synthetic varieties, 12.07; in F_1 crosses, group 1, 3.58; and in F_1 crosses, group 2, 5.71, whereas among the smutted plants the corresponding percentages were (column 7) 13.83, 13.0, 7.18, and 8.05 respectively. The differences in these percentages are appreciable (column 8) except the one for the synthetic varieties. In column 9 are shown the percentages of the total number of plants under observation that were smutted. The 1932 crop was considerably damaged by hail, but the data on relative barrenness among smutted and smut-free plants were similar to those obtained in 1933, although the incidence of smut was somewhat less during 1932. In this year the percentage of the total number of plants that showed smut boils among commercial varieties was 6.28; among synthetic varieties, 3.37; and among the F_1 crosses between synthetics, 3.94.

The location of the smut boils on barren plants is shown in Table 5. The total number of smutted barren plants studied in 1933 is shown in column 6 of Table 4. In 1932, the total number of barren smutted plants observed among the different sorts were as follows: Commercial varieties 16, synthetic varieties 30, and F_1 crosses between synthetics 107. It is apparent from Table 5 that in 1932 most of the barren plants were infected below the ear (columns 3 and 4), whereas in 1933 the greater infection occurred above the ear (columns 6 and 9). Ear infection (column 5), as one might expect, was an important cause of barrenness during both years. Inasmuch as the experiments in 1932 and 1933 were duplicates and conducted on the same plats of land, the difference in the results obtained must be due principally to season and probably to hail damage in particular. On July 7, 1932, a severe hail storm did considerable mechanical damage to the corn which at that time was about waist high. The abrasions caused by hail striking the lower part of the stalks which had developed at that time may have increased the incidence of smut in this region of the plant. Similar observations were made among the smutted plants that were not barren; i. e., smut boils occurred in a relatively high percentage of plants at "below ear" or "base" in 1932 and on the "neck" in 1933.

TABLE 4.—*The number of barren plants among smutted and smut-free corn plants grown on the agronomy farm near Morgantown, W. Va., in 1933.*

Name	Number of smut-free plants	Number of barren smut-free plants	Percentage of smut-free plants barren	Number of smutted plants	Number of barren smutted plants	Percentage of smutted plants barren	Difference between percentages	Percentage of plants smutted
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Commercial varieties	1,513	126	8.33	188	26	13.83	5.50	11.05
Synthetic varieties...	2,294	277	12.07	193	25	13.00	0.93	7.76
F_1 crosses, group I*..	4,862	174	3.58	529	38	7.18	3.60	9.81
F_1 crosses, group II*.	5,166	295	5.71	236	19	8.05	2.34	4.37

*Group I earlier maturing; group II later maturing.

TABLE 5.—*Location of smut boils on barren stalks.*

Name	Year grown	Percentage of total number of stalks showing smut infection at							
		Base	Below ear	Ear	Above ear	Leaf	Leaf sheath	Neck	Tassel
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Commercial varieties.....	1932	6.25	37.5	31.25	12.5	—	—	12.5	—
Synthetic varieties........	1932	3.33	56.67	26.67	10.0	—	—	—	3.33
F_1's between synthetic varieties.........	1932	14.02	36.45	25.23	11.21	1.87	—	7.48	3.74
Commercial varieties.....	1933	4.17	20.83	37.50	—	—	—	20.83	16.67
Synthetic varieties........	1933	—	5.26	21.05	5.26	5.26	5.26	36.84	21.05
F_1's between synthetic varieties........	1933	4.08	8.16	16.32	4.08	—	4.08	55.10	8.16

The results obtained in 1933 are probably more indicative of the reaction of the plants to smut that may be expected when grown under the conditions described during a season without hail.

HAIL DAMAGE AND YIELD

The hail storm of 1932 did considerable damage to the corn crop, but there were appreciable differences in extent of injury among individual plants. This presented an opportunity to make a study of the difference between yields (shelled corn) of paired plants, one of which was obviously damaged by hail and the other was not. All paired plants were adjacent in the same row and were free from smut boils. In Table 6 are shown the average yields (columns 3 and 4) and the differences between them (column 5) of 194 such paired plants among the group 1 F_1 crosses and 115 similar pairs among the group 2 F_1 crosses. The mean difference obtained in group 1 is 103.4 grams with a standard error of 8.3, and in group 2 125.4 grams with a standard error of 6. The differences in both cases are in favor of the plants not obviously damaged by hail. The reduction in average yield which may

TABLE 6.—*The average yields in grams of grain per plant of hail-damaged and not hail-damaged corn plants in first generation crosses between synthetic varieties grown on the agronomy farm near Morgantown, W. Va., in 1932.*

Group of F_1 crosses*	Number of pairs	Average yield in grams		Difference	Percentage reduction in yield due to hail
		Hail damaged	Not hail damaged		
(1)	(2)	(3)	(4)	(5)	(6)
I...........	194	76.0	179.4	103.4	57.6
II..........	115	76.7	202.1	125.4	62.0

*Group I earlier maturing; group II later maturing.

be attributed to hail damage was 57.6% in the group 1 crosses and 62.0% in the group 2 crosses (column 6). These estimates of reduction in yield are likely too low rather than too high because plants considered not obviously damaged may nevertheless have been damaged to some extent.

DISCUSSION AND SUMMARY

The data presented in this paper support those reported earlier from the West Virginia Experiment Station in showing that under the conditions described increased barrenness because of smut is the most important factor in reducing yield. In no case was a significant average difference in yield of forage or grain obtained between adjacent paired plants (smutted and smut-free) among the later maturing, first-generation crosses of synthetic varieties, even with those comparisons in which each one of the smutted plants carried at least one boil the size of a hen's egg or larger. On the other hand, among the earlier maturing F_1 crosses, of the six comparisons with yield of grain where size of smut boil was disregarded, two significant average differences in favor of the smut-free plant were obtained. When yield of forage was used as the criterion disregarding size of smut boil, no significant average differences were found. When comparisons were made only between paired plants, one of which carried at least one large smut boil, two (one for yield of grain and one for yield of forage) out of four average differences in favor of smut-free plants were found to be significant. These results suggest that smut injury may be more serious in early-maturing varieties such as would be grown in the northern part of the corn belt than among the later-maturing varieties.

In those cases where a significant reduction in average yield was obtained because of smut, the magnitude of the reduction was less than that obtained in the Minnesota investigation (3, 4). In Table 1, column 5, the 28.3 grams reduction in average yield is 17.2% of the average yield of the 39 smut-free plants in this comparison. Similarly, 31 grams in the same column represent 16.1% reduction in average yield. In Table 3, where comparisons were confined to heavily-smutted and smut-free plants, the two significant differences represent percentage reductions in yield of 15.4 (grain) and 10.4 (forage).

Contrary to what might be expected, smut boils located "above ear" and at "neck" caused more damage than those located "below ear" and "base." A similar observation was made by Immer and Christensen (3, 4). Of the four significant differences in average yield reported above, three were obtained between paired plants, one of which was smutted at the "neck," and the remaining difference was obtained between paired plants, one of which showed smut at the "base." The four comparisons of average yields of grain available for paired plants, one of which carried "tassel" smut (Table 1), show three differences in favor of the smutted plants, although these differences are not statistically significant.

Among the 57 barren smutted plants belonging to the first-generation crosses between synthetic varieties grown in 1933 (Table 5), 55.1% were smutted at the "neck." In 1932 smut located "below ear"

was predominantly associated with increased barrenness, but this may have been due to hail damage. During both years ear infection, as one might expect, accounted for considerable increased barrennes attributable to smut.

In contrast to the relatively small damage caused by smut in corn grown in 1932 and 1933 under the conditions described, a marked decrease in yield during the former year was caused by a hail storm that occurred on July 7. The decrease in average yield between paired plants attributable to hail injury was 57.6% among the earlier-maturing, first-generation crosses and 62% among the later-maturing ones.

LITERATURE CITED

1. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1932.
2. GARBER, R. J., and HOOVER, M. M. The relation of smut infection to yield in maize. Jour. Amer. Soc. Agron., 20:735–746. 1928.
3. IMMER, F. R., and CHRISTENSEN, J. J. Determination of losses due to smut infections in selfed lines of corn. Phytopath., 18:599–602. 1928.
4. ——————, ——————. Further studies on the reaction of corn to smut and effect of smut on yield. Phytopath., 21:661–674. 1931.
5. JORGENSON, L. R. Effect of smut infection on the yield of selfed lines and F_1 crosses in maize. Jour. Amer. Soc. Agron., 21:1109–1112. 1929.
6. KYLE, C. H. Relation between the vigor of the corn plant and its susceptibility to smut (*Ustilago zeae*). Jour. Agr. Res., 41:221–231. 1930.

THE AVAILABLE PHOSPHORUS AND POTASSIUM CONTENTS OF SURFACE SOILS AND SUBSOILS AS SHOWN BY THE NEUBAUER METHOD AND BY CHEMICAL TESTS[1]

S. F. THORNTON[2]

BOTH practical observations and scientific investigations have shown that subsoils usually are much less productive than surface soils. This is especially true for non-legume crops. However, the nature of the cause of the failure of plants to make satisfactory growth on subsoil material is still a disputed question. It has been attributed to lack of available nutrients, soil reaction, presence of toxic substances, lack of proper aeration, and undesirable physical conditions. Work on this problem during recent years has been confined largely to pot tests and field observations. Because of the large amount of work involved in such tests only a relatively few soils have been investigated.

EARLIER WORK

Alway, McDole, and Rost (1)[3] found that the subsoil material of Nebraska loess soils was unproductive with corn but showed no rawness towards inoculated legumes. They made the further observation that unproductivity of subsoils from humid regions towards inoculated legumes is probably due to lack of availability of phosphoric acid or potash, or both.

Lipman (8) immediately questioned the existence of humid subsoils which were sterile towards inoculated legumes and denied that lack of phosphoric acid or potash could be the cause of such unproductivity.

Harmer (3) found some of the humid Minnesota subsoils to be as productive with inoculated alfalfa as the corresponding surface soils. Others, however, he found quite unproductive. Such unproductivity was associated with neither an especially low nitrogen content nor a lack of carbonates.

McMiller (7) used alfalfa in pot tests to show that certain Minnesota subsoils which previously had been found "raw" towards inoculated legumes were rendered as productive as the corresponding surface soils when soluble phosphorus and potassium fertilizers were added.

Millar (4, 5, 6), from work with several soil types, concluded that the poor growth of corn in soil from A_2 and B horizons is due very largely to a lack of available nutrients and that very large quantities, particularily of phosphorus, must be added to satisfy the adsorptive capacity of the soil and make plant growth commensurate with that obtained when surface soil is used.

Conner (2) carried out pot tests with wheat on surface soil and subsoil horizons of Crosby and Clyde silt loam soils. Nitrogen and phosphorus were found to be very deficient in all subsoils as compared to surface soils. Potash and lime were less deficient than either nitrogen or phosphorus.

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[1]Contribution from the Department of Agricultural Chemistry, Purdue University Agricultural Experiment Station, Lafayette, Ind. From a part of a thesis submitted to the faculty of the Graduate School of Purdue University in partial fulfillment of the requirements for the degree of doctor of philosophy. Also presented at the annual meeting of the Society held in Washington, D. C., Nov. 22 and 23, 1934. Received for publication November 28, 1934.

[2]Assistant Chemist.

[3]Figures in parenthesis refer to "Literature Cited," p. 50.

THE PRESENT INVESTIGATION

In so far as the writer is aware no data are available to show the relative available phosphorus and potassium contents of a large number of surface soils and subsoils. Such data are necessary before general conclusions can be drawn regarding the relative mineral nutrient contents. It is hoped that the present work will serve as a contribution towards this end.

The chief difficulty in securing such data is in finding a method which is sufficiently simple and rapid to make possible a large number of determinations and that at the same time gives reliable indications of actual availability to plants. The Neubauer method has been found best to fulfill these requirements. Details of the procedure used have been given in an earlier work by the author (9). For comparative purposes, data are also given for chemical tests for both phosphorus and potassium. The procedures used are the rapid chemical tests recently described by Thornton, Conner, and Fraser (10). These tests indicate the relative amounts of dilute acid-soluble phosphorus and water-soluble and replaceable potassium.

The samples tested represent arbitrary depths rather than definite horizons, surface soils representing the top 6 to 8 inches and subsoils the second 6 to 8 inches. Thus, the surface soils represent approximately the cultivated area. All results are expressed in pounds per acre on the basis of 2,000,000 pounds.

Table 1 gives the average pH and the average Neubauer values for 460 soils listed according to the states from which they were obtained. With the exception of Indiana it is felt that the number of soils from each state is too small to be taken as definitely representative of average conditions. However, some important trends are indicated.

TABLE 1.—*Neubauer tests for 460 soils from various locations.*

Location	No. of samples	pH		Lbs. P_2O_5 per acre		Lbs. K_2O per acre	
		Surface soil	Subsoil	Surface soil	Subsoil	Surface soil	Subsoil
Indiana....	219	5.9	5.9	59	37	219	182
Ohio.......	31	5.9	5.9	49	27	212	214
Iowa.......	31	6.8	6.8	87	48	412	261
Kentucky...	16	6.1	6.0	78	60	339	315
Maryland...	74	6.1	6.0	72	57	337	249
California...	57	7.0	7.0	189	143	678	627
Misc.......	33	6.2	6.2	72	62	250	244
Average..	460	6.2	6.2	80	56	314	265

The average pH of the surface soils and the subsoils is practically identical in all cases and, for the majority of soils, is approximately 6.0. Definitely higher values are indicated for Iowa and California.

In comparison with the corresponding surface soils, the available phosphorus content of the subsoils is low in every instance. This is especially true for Indiana, Iowa, and Ohio. In contrast, the Cali-

fornia soils show much higher values for surface soils and also relatively high subsoil values.

The available potash content of the subsoil usually is found to be somewhat lower than that of the surface soil. However, this relation is neither as consistent nor as pronounced as for phosphorus. The California soils show unusually high values for both surface soils and subsoils.

Results of the chemical tests are given in Table 2. Because the upper range of the chemical tests is not as high as the values sometimes obtained with the Neubauer method, values in Table 2 are usually somewhat lower than those given in Table 1. This is especially true for potassium.

TABLE 2.—*Chemical tests.**

Location	No. of samples†	pH		Lbs. P_2O_5 per acre		Lbs. K_2O per acre	
		Surface soil	Subsoil	Surface soil	Subsoil	Surface soil	Subsoil
Indiana....	170	5.9	5.9	61	57	165	170
Ohio......	21	5.9	5.9	48	63	174	196
Iowa......	31	6.8	6.8	118	93	176	101
Kentucky..	15	6.1	6.0	46	40	252	222
Maryland..	74	6.1	6.0	70	34	246	161
California..	57	7.0	7.0	150	139	329	271
Misc......	32	6.2	6.2	104	101	178	162
Average.	400	6.2	6.2	82	70	209	180

*Described in Purdue Univ. Agr. Exp. Sta. Circ. 204. 1934.

†Samples of 60 of the soils reported in Table 1 had been exhausted and thus were not available for chemical tests.

For phosphorus the chemical tests do not give such relatively low values for subsoils, in most cases the values for surface soils and subsoils being quite close together. From these data it appears that the dilute acid-soluble phosphorus content of surface soil and subsoil is usually quite similar. In previous work it has been found that on surface soils such tests serve as reliable indicators of phosphorus availability, but on subsoils they tend to give values that are too high.

As was true for the Neubauer method, chemical tests indicate a slightly lower available potassium content for subsoils as compared to the corresponding surface soils.

Since a few very high results may raise markedly the average for a large number of samples, the average analysis does not always best express the true conditions. The relative number of samples which are deficient has been found to be a valuable supplement to the data already discussed. Table 3 contains such data. They serve to emphasize the points already advanced. Especial mention may be made of the high percentage of subsoils which are deficient in available phosphorus.

In Tables 4, 5, and 6 the Indiana soils have been grouped according to pH. No especially significant correlation between pH and available phosphorus or available potassium as shown by the Neubauer method

is to be observed. However, for both phosphorus and potassium and with both surface soils and subsoils slightly higher values are given in the 6.1 to 6.5 group. The greatest number of soils are to be found in the 5.6 to 6.0 group.

TABLE 3.—*Percentage of soils deficient in phosphorus and potash.*

Location	Surface soil				Subsoil			
	Phosphorus		Potash		Phosphorus		Potash	
	Neubauer	Chemical	Neubauer	Chemical	Neubauer	Chemical	Neubauer	Chemical
Indiana....	78	73	65	74	96	75	65	72
Ohio......	90	81	60	81	94	70	55	71
Iowa......	61	35	42	74	97	52	55	84
Kentucky..	70	80	19	47	75	87	19	67
Maryland..	70	70	45	50	81	93	51	73
California..	19	9	0	21	33	16	0	37
Misc.......	64	41	50	66	70	44	55	84
Average..	68	37	49	61	83	66	51	69

TABLE 4.—*Neubauer tests at different pH levels (Indiana soils).*

pH	Surface soil			Subsoil		
	No. of samples	Lbs. per acre P_2O_5	Lbs. per acre K_2O	No. of samples	Lbs. per acre P_2O_5	Lbs. per acre K_2O
——5.0	14	56	208	27	34	131
5.1–5.5	42	51	235	45	29	146
5.6–6.0	69	60	210	53	38	193
6.1–6.5	53	67	250	38	46	221
6.6–7.0	27	52	188	36	40	199
7.1——	11	65	143	15	36	190

TABLE 5.—*Chemical tests at different pH levels (Indiana soils).*

pH	Surface soil			Subsoil		
	No. of samples	Lbs. per acre P_2O_5	Lbs. per acre K_2O	No. of samples	Lbs. per acre P_2O_5	Lbs. per acre K_2O
——5.0	12	34	203	20	21	216
5.1–5.5	35	37	172	43	21	143
5.6–6.0	58	55	161	44	46	165
6.1–6.5	38	78	175	32	97	201
6.6–7.0	17	81	125	22	107	157
7.1——	7	124	132	7	120	123

Data for the chemical tests (Table 5) do show an interesting correlation with pH. For both surface soils and subsoils the available phosphorus content shows a gradual increase with increasing pH and a

TABLE 6.—*Percentage of soils (Indiana) deficient in phosphorus and potash.*

pH	Surface soils				Subsoils			
	Phosphorus		Potash		Phosphorus		Potash	
	Neubauer	Chemical	Neubauer	Chemical	Neubauer	Chemical	Neubauer	Chemical
—5.0	80	92	50	67	96	95	66	50
5.1–5.5	88	86	67	71	100	100	78	90
5.6–6.0	83	83	70	76	94	86	62	70
6.1–6.5	65	63	60	76	97	44	89	60
6.6–7.0	80	47	70	76	92	41	50	91
7.1—	64	14	82	86	100	57	87	71

marked increase when the neutral point is passed. The increase is more rapid with subsoils than with surface soils. It appears that such chemical tests may be expected to give somewhat low results for the very acid soils, somewhat high results for the neutral and slightly acid soils, and much too high results with alkaline soils. The results of such tests on alkaline soils have proved unreliable.

For potash there is a tendency for the chemical tests to give somewhat lower values with increasing pH.

From a comparison of the Neubauer and chemical test data it appears that for phosphorus solubility in dilute acids increases with increasing pH more rapidly than does availability to plants, while for water-soluble and replaceable potassium the reverse is true.

SUMMARY AND CONCLUSIONS

Comparative data for surface soils and subsoils are given for 460 soils with the Neubauer method and 400 soils with chemical tests.

With the Neubauer method, subsoils as compared to surface soils show a much lower available phosphorus content. For soils from the Middle West, subsoils are phosphorus deficient in almost all cases.

Neubauer values for available potassium are only slightly lower with subsoils than with corresponding surface soils.

With chemical tests subsoils appear to be relatively only slightly lower in available phosphorus and slightly lower in available potash.

With the Neubauer method there appears to be little correlation between pH and available phosphorus and potassium content.

With chemical tests the phosphorus values increase with increasing pH and the potassium values show somewhat the reverse tendency.

The data presented indicate that for subsoils of the humid regions at least, phosphorus deficiency is an important factor in the unproductivity so often observed.

LITERATURE CITED

1. ALWAY, F. J., MCDOLE, G. R., and ROST, C. O. The loess soils of the Nebraska portion of the transition region: VI. The relative rawness of subsoil. Soil Science, 3:9–35. 1917.
2. CONNER, S. D. Fertility tests of soil horizons. Rpt. 10th Ann. Meet. Amer. Soil Survey Assoc., Bul. XI:122–125. 1930.

3. HARMER, PAUL M. The relative rawness of some humid subsoils. Soil Science, 5:393–401. 1918.
4. MILLAR, C. E. The availability of nutrients in subsoils. Soil Science, 19:275–285. 1925.
5. ———. The feeding power of plants in different soil horizons. Jour. Amer. Soc. Agron., 17:150–156. 1925.
6. ———. Availability to corn of nutrients in the A_2 and B horizons of Hilsdale loam. Jour. Amer. Soc. Agron., 25:418–426. 1933.
7. McMILLER, PAUL R. Some notes on the cause of unproductivity of "raw" subsoils in humid regions. Soil Science, 7:233–236. 1919.
8. LIPMAN, CHAS. B. On the rawness of subsoils. Science, 46:288–290. 1917.
9. THORNTON, S. F. Experiences with the Neubauer method for determining mineral nutrient deficiencies in soils. Jour. Amer. Soc. Agron., 23:195–208. 1931.
10. ———, CONNER, S. D., and FRASER R. R. The use of rapid chemical tests on soils and plants as aids in determining fertilizer needs. Purdue Univ. Agr. Exp. Sta. Circ. 204. 1934.

NITROGEN, PHOSPHORUS, AND POTASSIUM REQUIREMENTS OF INDIANA SURFACE SOILS AND SUBSOILS[1]

S. D. CONNER[2]

OVER three-fourths of the agricultural lands of the country are more or less subject to erosion. The surface soils of today were the subsoils of yesterday, and it is safe to say that the subsoils of today will be the surface soils of tomorrow. Therefore, it is vitally important that we find the fertility possibilities of our subsoils. While natural forces gradually change the barren eroded soils into a much more productive condition, this is only a gradual change. If we know the deficiencies of subsoils, we are in a position to speed up this process. Chemical methods are of some value in determining the availability of soil constituents, but tests by means of growing crops are much more to be depended upon than is the solvent action of chemicals.

The work reported in this paper is a continuation of the investigations presented at the tenth annual meeting of the American Soil Survey Association held in Chicago in 1929 and published in Bulletin XI of that Association.

Complete fertility pot tests have been conducted with five Indiana surface and subsoils, the description and analysis of which are shown in Table 1. These soils vary from poorly drained to well drained and from thin high land to rich alluvial bottom land.

Ammonium nitrate, mono-calcium phosphate, potassium chloride, and calcium carbonate were mixed with the soils at the start, in various combinations, including complete treatment and in other combinations with one ingredient omitted. Nitrogen was added to the nitrogen pots for the second wheat crop. Minerals were applied only on the first crop.

Four crops were grown in succession on soils from four horizons of Crosby silt loam, a naturally level poorly drained type of upland soil. This soil was taken from the soils and crops experiment farm at Lafayette, Ind. It is now tile drained with the tiles about 3 feet deep and 59 feet apart. This soil has a rather heavy B horizon and the tile should be much closer to furnish adequate drainage. Fig. 1 shows the tile effect on corn on this land. Lack of drainage between tile lines prevents deep rooting of corn and other crops. On areas where little or no potash is applied, potash starvation causes depressed yields. This depressed growth of corn showing potash starvation symptoms is not seen where manure or fertilizer supplying adequate potash has been used. Root studies show that corn does not root much deeper than plow depth half-way between tile lines, but near the tiles it roots 3 or 4 feet deep, thus being able to secure potash as well as moisture from the subsoil.

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[1]Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. Also presented at the annual meeting of the Society held in Washington, D. C., November 22 and 23, 1934. Received for publication November 28, 1934.

[2]Research Chemist.

TABLE 1.—*Description of soils used in pot tests.*

Soil type	Depth in inches	Drainage	Neubauer tests		Chemical tests*			
			P	K	N, %	P	K	pH
Bethel silt loam...	0–6	Very poor			0.13	Very low	Very low	6.0
Bethel silt loam...	6–15	Very poor			0.09	Very low	Low	5.0
Crosby silt loam...	0–6	Poor	3.7	4.3	0.09	Low	High	5.5
Crosby silt loam...	6–15	Poor	2.9	6.5	0.04	Very low	Very high	5.7
Crosby silt loam...	15–30	Poor	2.9	9.1	0.04	Medium	Very high	6.3
Crosby silt loam...	36–48	Poor	4.8	9.1	0.03	High	Medium	8.0
Clyde silty clay loam..........	0–6	Good	5.1	9.1	0.20	High	High	6.2
Clyde silty clay loam..........	6–15	Good	2.2	9.7	0.08	Very low	Medium	6.4
Clyde silty clay loam..........	15–30	Good	1.5	9.7	0.04	Medium	Low	6.8
Warsaw loam.....	0–6	Very good	2.3	9.7	0.17	Very low	Low	5.6
Warsaw loam.....	6–15	Very good	2.2	10.9	0.10	Very low	Low	5.6
Genesee silt loam..	0–6	Good	7.7	31.5	0.29	High	Very high	8.0
Genesee silt loam..	6–15	Good	6.7	32.7	0.32	Low	Medium	8.0

*Phosphorus and potassium determined with rapid method, giving dilute acid soluble phosphorus and exchangeable potassium. See Purdue Univ. Agr. Exp. Sta. Circ. 204.

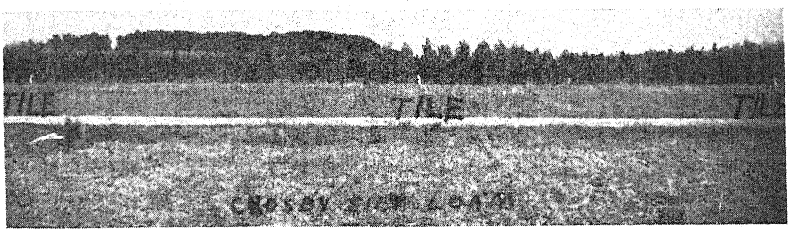

FIG. 1.—Corn on Crosby silt loam is much better near tile than it is between tile lines.

Fig. 2 shows the relative yields of the various crops on all horizons. The most striking point illustrated is the rapid decrease in yields of all crops the deeper the soil layer when phosphorus is omitted. This is also shown where nitrogen is omitted on wheat, but not with legumes. Where phosphate and nitrogen are added the subsoil horizons yield almost as much as the surface soil. When potash is omitted it is seen that in most cases the subsoils are able to furnish adequate supplies of potash. The PKCa treatment without nitrogen gave very small yields

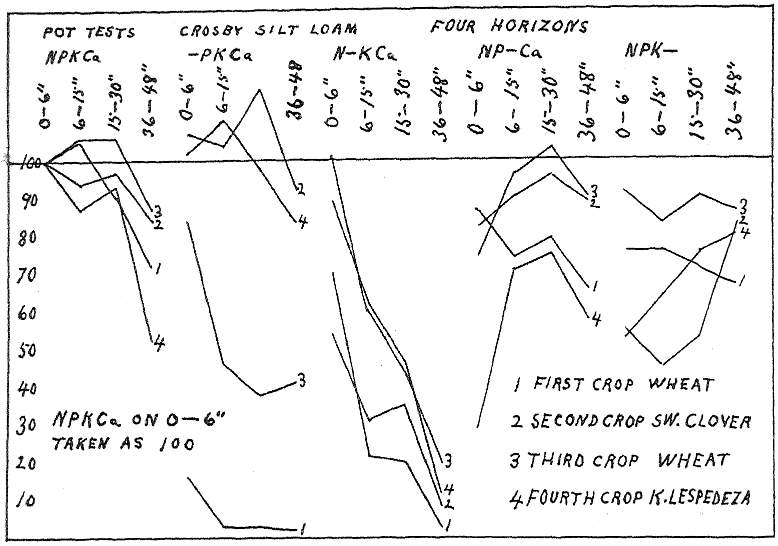

FIG. 2.—Relative yields of pot tests on four horizons of Crosby silt loam with four successive crops and various fertilizers.

with wheat, the first crop, even on the surface soil. This soil was taken from the field in October when nitrates were at a very low level. Other investigations as well as this show a very low nitrogen efficiency in

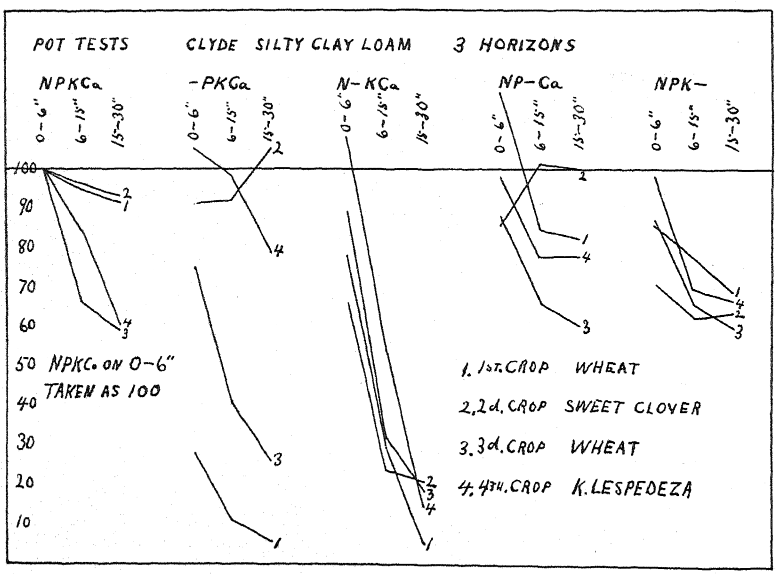

FIG. 3.—Relative yields of pot tests on three horizons of Clyde silty clay loam, with four successive crops and various fertilizers.

pot tests even on nitrogen-rich soils when soil is taken from the field in late fall or winter. In Fig. 2 it will be seen that the second wheat crop with PKCa is relatively at a very much higher level, particularly on the surface soil. While this may be partly explained as a legume effect, other tests where no legume was used show similar results.

Fig. 3 shows the results of pot tests on three horizons of Clyde silty clay loam, a naturally poorly drained high land depression soil, very rich in organic matter and of naturally high fertility. This soil is also

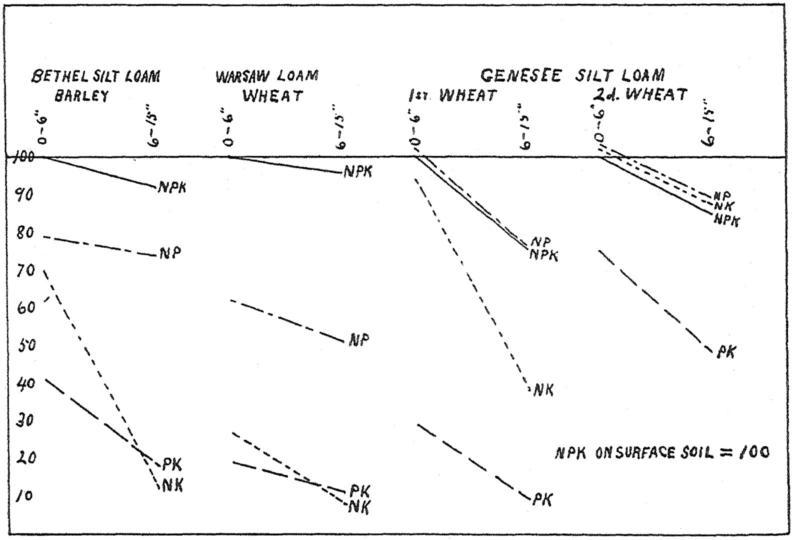

FIG. 4.—Relative yields of pot tests on three soils and two horizons, with various fertilizers.

from the soils and crops farm and is tiled and apparently now adequately drained, as it does not show the tile effect seen on the adjoining Crosby. These results show a very similar picture to that in Fig. 2; low nitrogen and phosphorus in the subsoils and good supplies of potash in the lower horizons. Neither of these soils nor their subsoils are acid enough to show any serious lime deficiency. What lime response there is seems to be relatively as great in the surface as in the subsoil horizons.

Fig. 4 gives results of pot tests on surface and subsoil horizons of three soils, using NPK, PK, NK, and NP treatments. The Bethel silt loam from Miami County is a flat, very poorly drained upland soil. The Warsaw loam is a level very well drained dark soil of prairie origin from Tippecanoe County. The Genesee silt loam is a well drained soil from the Wabash River bottoms. This soil is of rather recent origin. The subsoil is higher in organic matter and nitrogen than the surface soil.

The level and slope of the graphs for each fertilizer treatment indicate that, in general, nitrogen and phosphorus are relatively more

deficient in the subsoils than in the surface soils. With the PK treatment on the Genesee soil, the second wheat crop is relatively much better than the first wheat crop in both the surface and subsoil. In this comparison there is no legume crop to add nitrogen. The greater efficiency of the soil nitrogen in the second crop over the first is due to other effects, probably aeration and nitrification. A similar change in efficiency of soil phosphorus may be observed in the NK yields, the second wheat crop showing no response for phosphate in the subsoil, while there was a distinct lack of phosphate in the first wheat crop.

The tendency for the phosphorus and sometimes the nitrogen of soils and subsoils to increase gradually in efficiency as they are exposed to drying aeration and heat in the greenhouse in the summertime between crops has often been noted in pot experiments when the same soil has been cropped for more than one year. This increase in availability is one method nature may have in causing old eroded soils gradually to accumulate available nitrogen and phosphorus.

SUMMARY

In general, when Indiana subsoils are tested in pot cultures, they show a greater need than do the surface soils for phosphorus for both legumes and nonlegumes. This need is often greater the further from the surface the soil is taken.

Nitrogen is more deficient for grain crops in subsoils than it is in surface soils. Subsoils did not show a deficiency of nitrogen when inoculated legumes were grown.

When more than one crop was grown on the same subsoil, the first crop was relatively more in need of nitrogen and phosphorus than were the succeeding crops.

Eroded surfaces and subsoils exposed in regrading operations or in fills using subsoil, are in need of liberal phosphate and nitrogen fertilization when seeded down to nonlegumes. Legumes on such surfaces should be inoculated and heavily fertilized with phosphates. Lime is of course needed where the soil is acid.

Potash may in some cases be needed on eroded surfaces, but in general, Indiana subsoils are in no greater need of potash than are surface soils.

PASTURING ALFALFA IN MICHIGAN[1]

H. C. Rather and A. B. Dorrance[2]

THIS discussion of some phases of alfalfa pasture under Michigan conditions is based primarily on experiments conducted at the W. K. Kellogg Farm of the Michigan State College located at Augusta, in southwestern Michigan. To check on some of the general principles which these trials have indicated, questions regarding them were taken up in some detail with 35 Michigan farmers regularly using alfalfa for pasture. The idea is not advanced that the opinions of these men accurately indicate the collective judgment of all Michigan farmers who have opened their alfalfa meadows to their livestock. Rather, a few of their ideas, summarized, are presented as an interesting and significant expression by men with an average of more than 10 years' experience in the use of alfalfa for pasture under conditions demanding the economic soundness of the enterprise.

ALFALFA VS. SWEET CLOVER FOR PASTURE

By ratio of 30 to 2 these farmers expressed their preference for alfalfa over sweet clover as a pasture crop.

"It is just as easy to get a stand with alfalfa as with sweet clover," they say, "alfalfa lasts more years, provides a longer grazing season, better and more palatable forage." The fact that second-year sweet clover is through as a pasture crop by about July 15 in Michigan, although the grazing season is only half over, is an important disadvantage. Pasture returns may normally be expected from sweet clover only in its second year, for much of Michigan's soil is of the lighter types on which this crop does not make enough growth during the year it is seeded to provide any fall pasture.

Typical of many areas in southwestern Michigan is the Bellefontaine sandy loam soil at Augusta on which a comparison of alfalfa and sweet clover pasture gave results in support of the preference of these farmers for alfalfa.

The seedings of alfalfa and sweet clover were made in duplicate 1-acre paddocks in 1930, following a 1929 application of 7 yards per acre of marl and treatment with commercial fertilizer. In 1931 the alfalfa furnished 613 sheep-days pasture per acre, the sweet clover 343. Both stands were good but even during June and July the alfalfa furnished the greater amount of pasture, while in August and September the sweet clover yielded nothing at all. Two years later the same sweet clover paddocks again were ready for grazing, this time in comparison with the old alfalfa already closely cropped by sheep for two seasons.

[1]Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich., and the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Journal Article No. 192 (new series) of the Michigan Agricultural Experiment Station. Also presented at the annual meeting of the Society held in Washington, D. C., November 22 to 23, 1934. Received for publication December 3, 1934.

[2]Head of Farm Crops Section, Michigan Agricultural Experiment Station, and Assistant Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, respectively.

The alfalfa yielded 821 sheep-days of pasture per acre, while 590 sheep-days were secured from the sweet clover.

ALFALFA AND PERMANENT GRASS PASTURES COMPARED

Permanent grass pastures in Michigan consist primarily of Kentucky bluegrass with a natural mixture of white clover, under favorable conditions. On the poorer soils Canada bluegrass is likely to predominate. The old meadows at Augusta are typical of those in southwestern Michigan, rolling in contour and running to Canada bluegrass and sorrel. Fertilization and reseeding has made possible the reestablishment of Kentucky bluegrass but, during the past 5 years, mostly dry years, white clover has failed to make a showing. On such an area, another field of Bellefontaine sandy loam soil, alfalfa pasture was compared with old grass pastures and newly seeded ones, the grasses being grown with and without fertilizer and lime treatments. The grazing results are given in detail for 1932 in Table 1, carrying capacity for 3 years in Table 2, and the fertilizer, lime, and seeding treatments in Table 3.

TABLE 1.—*Comparison of pasture returns from alfalfa and permanent grass pasture, W. K. Kellogg farm, Augusta, Mich., 1932.**

Crop	Lamb-days per acre	Gain, lbs. per acre	Total lbs. of grain fed per acre	Value of barley consumed per acre of pasture at 30 cents per bushel	Total value of gains at 5.5 cents per pound	Acre returns from pasture less cost of grain	1932 fertilizer charges†	Returns after deducting grain costs and 1932 fertilizer charges
Alfalfa......	1,873.5	392.3	1,028	$6.42	$21.58	$15.16	$4.83	$10.33
Pasture mixture, two nitrogen applications.....	1,367.0	259.3	643	4.02	14.26	10.24	9.07	1.17
Fertilized sod	698.0	179.0	370	2.31	9.85	7.54	8.02	—0.48
Pasture mixture, one nitrogen application......	1,120.5	122.6	413	2.58	6.74	4.16	8.02	—3.86
Unfertilized sod........	456.5	99.5	298	1.87	5.47	3.60	None	3.60
Unfertilized pasture mixture.......	459.5	85.9	280	1.75	4.72	2.97	None	2.97

*From Dorrance, A. B., Brown, G. A., and Rather, H. C. Experiments with permanent pasture for sheep. Mich. Exp. Sta. Quart. Bul., 15, No. 2. 1933.

†Fertilizer charges made against 1932 returns are all costs of nitrogen applied in 1932, 60% of the 0–14–14 applied in 1932, and ⅓ of the 2–16–6 applied in 1930. All other fertilizers previously applied are chargeable to previous seasons.

TABLE 2.—*Comparative carrying capacity of alfalfa and permanent grass pasture at the W. K. Kellogg Farm, Augusta, Mich., 1931, 1932, and 1933.*

Crop	Carrying capacity in terms of sheep-days per acre*			
	1931	1932	1933	Average
Alfalfa	613	937	821	790
Pasture mixture, two nitrogen applications	552	684	558	598
Fertilized sod	608	349	279	412
Pasture mixture, one nitrogen application	379	560	308	416
Unfertilized sod	222	228	251	234
Unfertilized pasture mixture	207	230	329	255

*Where lambs were used, two lambs were considered the equivalent of one ewe in determining a "sheep-day".

At the beginning of the 1933 grazing season timothy had passed out of all the paddocks where it was sown in 1930. At this time there was a pure sod of Kentucky bluegrass on those paddocks receiving nitrogen twice a year, a mixture of red top and Kentucky blue grass with a small amount of Canada bluegrass on those receiving nitrogen only in the spring, and almost pure red top on the unfertilized areas originally seeded to the pasture mixture. The old sods consisted mostly of Canada bluegrass and, in unfertilized paddocks, weeds.

This was not primarily a fertilizer experiment but rather a comparison of different pasture crops. That alfalfa on limed and fertilized soil should outyield native grass pastures without such treatment was to be expected. However, the fertilization of these old pastures or the establishing of new grass pastures on this land by reseeding and fertilization has thus far failed to yield returns in relation to costs comparable to those from alfalfa pasture. Furthermore, the major part of the increase in yield of the fertilized grass pastures has come in the moist months of the spring. With the advent of the dry hot weather of July and August the fertilized grasses have quit growth just as completely as the unfertilized and have yielded only small amounts of summer pasturage in some seasons, none at all in others. Alfalfa has been more productive of pasturage than these grasses both in the spring and in the summer.

The results for the 1932 season are presented in greater detail because a uniform group of western lambs was used in pasturing off the various paddocks and comparative gains of these lambs add to the significance of the results. Also, the summer of 1932 was fairly favorable to grass pastures from a moisture standpoint, there being 4.11 inches of rainfall in July and 2.83 inches in August, the latter nearly normal and the former 0.95 inch above normal. In every other year of these comparisons rainfall for July and August was substantially below

TABLE 3.—*Record of seedings and treatments of paddocks listed in Tables 1 and 2.**

Crop		Seeding		Fertilizer treatments				
No.	Kind	Kind	Rate in lbs. per acre	1929	1930	1931	1932	1933
1	Alfalfa	Grimm	10	300 lbs. per acre 2-16-6	300 lbs. per acre 2-16-6	None	300 lbs. per acre 0-14-14	None
2	Pasture mixture, two nitrogen applications	Kentucky bluegrass Canada bluegrass Red top Timothy Alsike Red clover White clover	6 3 3 4 2 2 2	300 lbs. per acre 2-16-6	300 lbs. per acre 2-16-6 100 lbs. of nitrate of soda in early July	100 lbs. sulfate of ammonia in spring; 100 lbs. nitrate of soda in early July	300 lbs. per acre 0-14-14; 100 lbs. sulfate of ammonia in spring; 100 lbs. nitrate of soda in early July	100 lbs. sulfate of ammonia in early spring; 100 lbs. nitrate of soda in early July
3	Fertilized sod	None	—	300 lbs. per acre 2-16-6	300 lbs. per acre 2-16-6	100 lbs. sulfate of ammonia in spring	300 lbs. per 0-14-14; 100 lbs. sulfate of ammonia in spring	100 lbs. sulfate of ammonia in spring
4	Pasture mixture, one nitrogen application	Same as No. 2	Same as No. 2	Same as No. 3	Same as No. 3	Same as No. 3	Same as No. 3	Same as No. 3
5	Unfertilized sod	None		None	None	None	None	None
6	Unfertilized pasture mixture	Same as No. 2	Same as No. 2	None	None	None	None	None

*All paddocks for numbers 1, 2, 3, and 4 were limed with 7 yards of marl per acre in 1929. Numbers 5 and 6 were unlimed and were strongly acid. All seedings failed in 1929 because of drought, and repetition of original fertilizer and seeding treatments was made in 1930. Seedings in 1930 were successful.

normal and the advantages of the alfalfa during these dry periods were even more marked than in 1932.

It may be added that the experience of those Michigan farmers questioned on alfalfa pasture is in accord with the results of this comparison, for 27 out of 28 stated that their grazing returns from alfalfa were far superior to those from permanent grass pasture.

MANAGEMENT OF ALFALFA FOR PASTURE

So many problems are involved in the management of alfalfa pasture that a single experiment must be limited in its application. Grimm alfalfa seeded on a Fox sandy loam soil at Augusta in 1929 was used to obtain information on the carrying capacity and suitability of alfalfa pasture for dairy cows and the influence of pasturage on the alfalfa as compared with cutting the crop for hay. The stand was established with a nurse crop of Spartan barley after the soil had been limed with 7 yards of marl per acre and fertilized with 300 pounds per acre of 2–16–6. The 1930 crop was cut for hay and grazing comparisons were started in 1931 in accordance with plans described in Table 4.

CONTINUOUS GRAZING

Michigan farmers, who have little or no grass land for permanent pasture, depend on shorter-lived crops throughout the grazing season. Rye, sweet clover, Sudan grass, and alfalfa are commonly used, and on such a farm it is desirable to use alfalfa for pasture in the spring as well as in the summer. Sometimes pasturage on alfalfa is started as early as May 1, though more frequently farmers report that they wait until May 15 to 25.

The number of animals on the pasture should be large enough to prevent the plants from maturing too quickly. In the 1930 trials at Augusta the start of grazing was delayed and the number of animals held down and as a result the alfalfa matured, became unpalatable, and produced only 66 cow-days of pasture for the season. In 1932 and 1933 grazing was started earlier and the number of cows adjusted so as to keep about an 8- to 12-inch growth of alfalfa. E. W. Ruehs, a Kent County dairyman who follows a similar practice with his Holsteins, states, "I think when you can't go in an alfalfa pasture field with a mower and rake and get hay you can't expect a dairy cow to get enough so she can give her daily 40 pounds of milk." At Augusta, under this system, the carrying capacity ranged from 122 to 142 cow-days per acre, using a pure-bred Guernsey herd, and gross returns from the alfalfa were as large as or larger than from any other combination of haying and grazing.

GRAZING THE FIRST CUTTING

It was thought that pasturing off the first growth of alfalfa and cutting the second for hay might have a place in a system of management where cows were transferred from one field to another. In the trials of this practice good pasture returns were secured, ranging from 77 to 96 cow-days per acre for the latter part of May and most of June. However, the hay produced afterwards was inferior and weedy, the cows letting many weeds grow which a mower would have cut.

TABLE 4.—*Alfalfa pasture management experiment.*

Method of handling	Year	Yield, lbs. air-dry hay per day		Cow-days pasture per acre	Milk produced per acre while cows were on pasture, lbs.	Value of milk testing 4.6%	Grain fed to cows while on pasture, lbs.	Cost of grain	Cash crop value of hay	Gross returns, i.e., cash value of hay per acre plus value of milk produced on pasture less cost of grain fed to cows on pasture*
		First cutting	Second cutting							
Continuous grazing	1931	—	—	66	2,224	$27.80	556	$7.17	—	$20.63
	1932	—	—	142	4,033	40.81	432	4.32	—	36.49
	1933	—	—	122	3,628	36.71	434	4.34	—	32.37
Grazed 1st cutting; 2nd cutting for hay	1931	—	200	78	2,717	33.96	679	8.76	$1.20	26.40
	1932	—	1,931	77	2,409	24.37	None	0.00	5.79	30.16
	1933	—	1,142	96	1,744	17.65	None	0.00	4.57	22.22
1st cutting for hay; 2nd cutting grazed	1931	2,600	—	30	1,087	13.59	271	3.50	15.60	25.69
	1932	3,982	—	111	2,920	29.55	730	7.30	11.95	34.20
	1933	3,435	—	80	2,202	22.28	500	5.00	13.74	31.02
Harvested for hay, 2 cuttings	1931	2,190	411	—	—	—	—	—	15.61	15.61
	1932	3,589	2,510	—	—	—	—	—	18.30	18.30
	1933	3,570	1,088	—	—	—	—	—	18.82	18.82

*Grain prices: 1931, $1.29 per cwt.; 1932, $1.00 per cwt.; 1933, $1.00 per cwt. Hay prices: 1931, $12.00 per ton; 1932, $6.00 per ton; 1933, $8.00 per ton. Milk prices: 1931, $1.29 per cwt.; 1932 and 1933, 22c per lb. for butter fat.

GRAZING SECOND CUTTING ALFALFA

One of the most common farm practices is to take the first cutting of alfalfa for hay and pasture the subsequent growth. A farm following this practice might have abundant spring and early summer pasture from permanent grass which, for so much of Michigan, is nonproductive when the dry hot weather comes. Some farmers have a sufficient acreage of alfalfa so the first cutting will ordinarily meet all their hay requirements leaving the second cutting for summer pasture and for sale of hay when there is more pasture than is needed.

This system worked well in the Augusta trials. The first cutting of hay was of good quality and its removal controlled most of the annual weeds; the second gave pasture in July and August when there was no grass pasture and without alfalfa the stable feeding of hay and summer silage would have been necessary. Even in 1932, when summer rainfall above normal made possible the production of 111 cow-days of pasture per acre from second-growth alfalfa, there was essentially no July or August grazing from the ordinary permanent grass pastures.

ENDURANCE OF PASTURED ALFALFA

It is not the intention here to compare returns from pastured alfalfa with those from alfalfa cut for hay. Both pasture and hay are needed, for there must be winter forage as well as summer forage. The paddock cut for hay twice each season was used as a check on the condition of stand of the pastured alfalfa. To give the alfalfa in those paddocks being grazed to capacity a chance to recuperate before winter, grazing on them was generally discontinued by September 1. Until the spring of 1934 there appeared to be no great difference in the condition of the alfalfa under each treatment. The stand cut for hay was probably somewhat cleaner than the others and the alfalfa grazed continuously appeared a little less vigorous than did the alfalfa in the other paddocks. Where the second cutting was pastured off it will be noted (Table 3) that the first cutting for hay yielded as much in 1933 as did the first cutting from the area used exclusively for hay.

September 1 was rather arbitrarily set as the date to discontinue grazing because this month in Michigan is the time when alfalfa makes its fall storage of root reserves and close grazing or mowing in September is injurious to the alfalfa. This was demonstrated at Augusta when, in the fall of 1933, the cows pasturing the alfalfa from which a first cutting had been taken for hay (area No. 3) were left on it until September 13. The winter of 1933–34 thinned out all the alfalfa, including that cut only for hay, so much that the stands were no longer considered useful. However, plat No. 3, for 3 years fully equal to the hay plat when grazing was stopped September 1, was injured most of all when it alone was closely pastured to September 13.

A more detailed study of fall clipping and grazing is underway at East Lansing which has given preliminary results supporting the belief that mowing or close grazing alfalfa in September is decidedly injurious to the vigor of the crop. This need not necessarily indicate

that all alfalfa pasturage must stop by September 1 for hay meadows may be available on which cows can be grazed at the rate of 1 animal on 3 to 5 acres, in which case serious injury to the alfalfa is unlikely. In fact Michigan farmers using alfalfa for pasture do continue to use it moderately throughout the fall months with success.

It will be noted that the alfalfa used in the Augusta trials lasted 4 years, 1 for hay and 3 under the different grazing practices. The very severe winter of 1933–34 killed the alfalfa sooner than will generally be the case. Three farmers reported having pastured the same stands of alfalfa 10 years and stated that they were still pretty good pastures. The average reported by the group of 35 farmers, however, was 3.4 years, the usual range being 2 to 4 years, but these figures do not quite give the whole story for many of these farmers harvested their alfalfa only for hay for 1, 2, or more years before using it for pasture. There is much farm opinion in Michigan to support the contention that if alfalfa is pastured judiciously, avoiding very close grazing at all times and permitting as much fall growth as is secured in hay fields, the pasturing will not prove materially harder on it than harvesting the crop exclusively for hay.

THE PROBLEM OF BLOAT

We are concerned not merely with injurious effects which grazing alfalfa may have on the stand but also with possible dangers to the livestock. The bugaboo of the farmer pasturing cattle or sheep on alfalfa is bloat. Many farmers using the crop for pasture have experienced losses, occasionally severe ones. Likewise, bloat losses have been reported on sweet clover, red clover, white clover, soybeans, and rye. Since information on bloat is largely empiric, general farm observations furnish about as reliable information as we have on this problem. Of farmers questioned on bloat, 19 out of 35 reported losses on alfalfa pasture. However, only one had discontinued the use of the crop as pasture because of bloat losses. Nearly all of these men attributed their difficulties to "slip-ups" in management which had permitted the animals to become excessively hungry. When precautions were carefully adhered to, the general opinion of these men was that extra returns from pasturing alfalfa outweighed its dangers.

The most common precautions for the avoidance of bloat were designed to keep the animals from working up too big an appetite and included (a) a full feed for the animals before first being turned on the alfalfa, (b) avoidance of grazing the first new growth, (c) keeping the stock on alfalfa pasture constantly once it was started on it, and (d) the providing of water and salt in or very near the field at all times. Another precaution is that certain animals appear unduly susceptible to bloat and, once discovered, should be kept off alfalfa pasture entirely.

SUMMARY

Experiments at Augusta, Michigan, and the summarized opinions of 35 farmers experienced in pasturing alfalfa are drawn on for information on the utilization of this crop for grazing purposes.

Alfalfa is a more desirable pasture crop than sweet clover in the opinion of nearly all of these farmers, an opinion which is supported by experimental evidence at Augusta. The advantages of alfalfa lay in greater carrying capacity, longer life, longer grazing season, and higher palatability.

Alfalfa has also proved superior to the usual permanent grass pastures on upland Michigan soils because of greater productivity and continued growth during hot dry periods of the summer when grasses were relatively non-productive.

In the Augusta experiments alfalfa pastured continuously proved productive as did that on which the first cutting was taken for hay and the subsequent growth pastured. Pasturing the first growth and harvesting the second for hay was less desirable on account of the annual weed growth in the hay and the fact that this system fails to take full advantage of alfalfa's drought resistance.

The heavy grazing of alfalfa in September proved injurious. Alfalfa on which heavy grazing was discontinued by September 1 came through each winter in nearly as good condition as that from which two cuttings of hay had been removed each season.

Some individual farmers reported having pastured the same stand of alfalfa for 10 years, the average for a group from widely distributed Michigan locations being 3.4 years.

The danger of bloat with cattle or sheep pasturing on alfalfa is prevalent. Most common precautions employed by Michigan farmers to avoid it are (a) to give animals a full feed before first turning them on alfalfa pasture, (b) to keep stock off the first new growth, (c) to keep stock on alfalfa pasture constantly once started on it, and (d) to provide water and salt in or very near the field at all times.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, VI[1]

T. R. STANTON[2]

THE last report on the registration of improved oat varieties was published in 1931.[3] No varieties were submitted for registration in 1932 and 1933. The improved varieties of spring oats approved for registration in 1934 are as follows:

Group and Varietal Name	Registration No.
Midseason white:	
Lenroc	80
Rusota	81
Spooner	82

Information on description and performance of these varieties, on which approval for registration is based, is summarized herein for the benefit of those interested in the production of better oats by growing improved varieties.

LENROC, REG. NO. 80

Lenroc (C. I. no. 3205) was originated as a plant segregate from a cross of Great American (Silvermine type) X Cornellian (Reg. No. 50) made in 1918 by W.T. Craig at Ithaca, N. Y. It was subsequently developed by the Department of Plant Breeding, College of Agriculture, Cornell University, by H. H. Love and W. T. Craig in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Lenroc is being multiplied for introduction to farmers in 1935. Application for its registration was made by the Department of Plant Breeding, Cornell University.

Lenroc is a midtall to tall, midseason white oat, with equilateral panicle. The kernels (caryopsis with hull) are similar in conformation to those of the Cornellian parent, but are white; about 50% of the lower florets of the spikelets carry a slightly twisted, semi-geniculate awn.

The superior characters of Lenroc are high yield and white kernels. It is the equal of Cornellian in productiveness, and in sections where there is objection to the gray kernels of Cornellian, Lenroc should replace it.[4]

Lenroc has been tested in replicated rod rows at Ithaca for 11 years. The annual and average yields of Lenroc and Cornellian are given in Table 1.

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[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 6, 1934.

[2]Senior Agronomist in Charge of Oat Investigations, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1934 Committee on Varietal Standardization and Registration charged with the registration of oat varieties.

[3]STANTON, T. R. Registration of varieties and strains of oats, V. Jour. Amer. Soc. Agron., 23:1013–1017. 1931.

[4]The performance and probable value of Lenroc also are discussed briefly in the Report of the Chief of the Bureau of Plant Industry, U. S. Dept. of Agriculture, 1934.

TABLE 1.—*Annual and average acre yields of Lenroc and Cornellian oat varieties grown at Ithaca, N. Y., 1924–34.*

Variety	Acre yield, bushels											
	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	Average
Lenroc...........	79.8	86.4	83.0	81.7	66.8	24.0	66.2	65.5	45.7	28.5	55.3	62.1
Cornellian........	76.2	88.2	84.5	76.6	67.2	25.0	64.4	61.4	44.9	28.7	52.1	60.8

RUSOTA, REG. NO. 81

Rusota (N. Dak. No. 20014, and C. I. No. 2343) was originated as a pure line from Green Russian and subsequently developed at the North Dakota Agricultural Experiment Station, Fargo, N. Dak. The original plant selection was made by T. E. Stoa of that institution in 1922, who also submitted the application for registration. Rusota will be distributed to farmers in northeastern North Dakota in 1935.

It is a midseason white variety with equilateral panicles and differs mainly from the Green Russian parent in having white kernels. Its superior characters are high yield, moderate resistance to stem rust, low percentage of hull, and white kernels. In a letter submitting the application Professor Stoa commented on the variety as follows:

> "I believe that it should be pointed out that this variety is recommended particularly for northeastern North Dakota and northwestern Minnesota where best results have been obtained. In sections further south an earlier maturing variety is preferable. In sections where rust may be less common the rust susceptible varieties may do about as well. The variety would class as a midseason but slightly earlier than Victory, averaging at Fargo 85 days to maturity compared with 86 for Victory and 79 for Gopher. In height Rusota averages only slightly shorter than Victory and has a moderately stiff straw."

Rusota has been tested in replicated field plats at several stations. Average acre yields of Rusota as compared with Victory, Rainbow, Gopher, Anthony, and Iogold, all standard improved varieties, are presented in Table 2.

TABLE 2.—*Comparative average yields from field plats of Rusota and leading standard varieties at experiment stations in North Dakota, northwestern Minnesota, and southern Manitoba.**

State or Province and station	Years for which data are presented	Variety and average acre yield, bushels					
		Rusota	Victory	Rainbow	Gopher	Anthony	Iogold
North Dakota:							
Dickinson	1928 to 1934	29.0	28.3	31.3	31.0	—	31.2
Edgeley	1927 to 1932	63.2	49.8	73.3	57.5	—	—
Fargo	1925 to 1932	75.9	68.4	79.1	77.2	—	—
Fargo	1927 to 1932	69.0	62.4	74.6	72.1	72.9	71.6
Langdon	1927 to 1934	64.9	62.3	64.1	51.4	—	—
Mandan	1928 to 1932	37.4	38.2	37.5	36.4	—	39.3
Minnesota:							
Crookston	1927 to 1934	71.4	58.3	64.5	60.1	68.4	—
Manitoba:							
Brandon	1930 to 1933	92.2	81.2	87.9	81.7	—	—

*Data from Mandan, Crookston, and Brandon presented through the courtesy of agronomists in charge of those stations.

TABLE 3.—*Annual and average yields of Spooner and Swedish Select oat varieties grown at the Spooner Substation, Spooner, Wis., 1917 and 1919–32.**

Variety	Acre yield, bushels														
	1917	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	Average, 15-years
Spooner......	61.8	40.6	51.5	6.0	48.1	34.5	26.7	41.1	21.9	45.3	45.6	34.6	42.3	19.0	31.5	36.7
Swedish Select	47.5	32.5	40.0	4.7	41.0	29.0	22.5	38.2	17.5	42.7	43.6	36.4	41.2	11.5	28.3	31.8

*Owing to the curtailment of work because of the World War no varietal experiments were conducted at Spooner in 1918.

SPOONER, REG. NO. 82

Spooner (Wis. No. S-405 and C. I. No. 3165) was originated at the Spooner Substation of the Wisconsin Agricultural Experiment Station as a pure line from Wisconsin No. 8 (Silvermine type). The original plant selection was made by E. J. Delwiche in 1913 under whose direction the variety was subsequently developed. The variety is named in honor of the late U. S. Senator John C. Spooner of Wisconsin. Application for registration of Spooner was made by E. J. Delwiche. The variety was first distributed for growing on farms in Wisconsin in 1924. It is especially well adapted to the light soil types of central and northern Wisconsin.

Spooner is a midseason white variety with equilateral panicles. Its superior characters are high-yielding power on sandy soils, mid-season maturity, stiff straw, and drought resistance.

Spooner has been tested in duplicated field plats at the Spooner Substation for 15 years. Table 3 presents the annual and average yields of Spooner as compared with those of Swedish Select (Wis. No. 5), a standard variety, for the years 1917 and 1919–32 at Spooner.

REGISTRATION OF IMPROVED WHEAT VARIETIES, VIII[1]

J. ALLEN CLARK[2]

SEVEN previous reports present the registration of 273 varieties of wheat. There were no registrations in 1933. In 1932, three varieties were registered, and the previous registration was referred to as in former years.[3]

Varieties approved for registration in 1934 are as follows:

Varietal Name	Registration No.
Relief	274
Rio	275
Rex	276
Thatcher	277
Sturgeon	278

RELIEF, REG. NO. 274

Relief (Utah 43e21, C. I. No. 10082) was produced by the Utah Agricultural Experiment Station from a cross between Hussar (female) and Turkey (male). The cross was made in 1925 and the selection from which Relief descended was made in 1928. The breeder, D. C. Tingey, applied for its registration.

Relief is a hard red winter wheat, resistant to most of the physiologic forms of bunt occurring in Utah. Relief was first grown in replicated nursery rows in 1929, in plat experiments in 1930, and commercially since 1931. The comparative data upon which registration is based are shown in Table 1.

TABLE 1.—*Comparative yields of Relief and other winter wheats grown in nursery and plat experiments at Newton, Utah.*

Variety	Yield in bushels per acre					Average	Percentage of Utah Kanred
	1929	1930	1931	1932	1933		
Nursery Experiments							
Relief (new)	49.3	36.3	33.3	32.6	19.0	34.1	110.0
Utah Kanred	38.5	35.5	38.4	22.5	20.0	31.0	100.0
Goldcoin	37.9	35.8	26.1	7.3	10.3	23.5	75.8
Plat Experiments							
Relief (new)	—	34.7	36.8	27.6	29.1	32.1	111.1
Utah Kanred	—	30.9	36.2	22.2	26.2	28.9	100.0
Goldcoin	—	21.8	28.8	20.0	20.7	22.8	78.9

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 6, 1934.

[2]Senior Agronomist, Wheat Investigations, U. S. Dept. of Agriculture. Member of the 1934 Committee on Varietal Standardization and Registration of the Society charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, VII. Jour. Amer. Soc. Agron., 24:975–978. 1932.

TABLE 2.—*Comparative smut data from Utah and from regional smut nurseries, 1932.*

Location	Variety						
	Relief	Utah Kanred	Gold-coin	Oro	Ridit	Hussar	Hybrid 128
	Utah Experiments						
Paradise	0.6	60.0	80.1	—	—	—	—
Clarkston	0.0	43.6	—	—	—	—	—
Wellsville	0.0	15.3	52.6	—	—	—	—
Newton	0.0	5.1	37.5	—	—	—	—
North Logan	0.1	34.5	76.0	—	—	—	—
Average	0.1	31.7	61.6	—	—	—	—
	Regional Experiments						
Newton, Utah	1.4	—	—	10.1	7.6	0.0	41.6
Moscow, Idaho	5.9	—	—	17.2	16.4	10.3	95.7
Felt, Idaho	3.0	—	—	3.5	2.2	3.5	65.2
Rockland Bench, Idaho	1.6	—	—	3.3	4.5	1.0	50.8
Pendleton, Oreg.	0.9	—	—	9.7	9.7	2.2	92.5
Moro, Oreg.	0.2	—	—	1.5	4.4	1.5	72.0
Corvallis, Oreg.	10.0	—	—	3.2	7.0	12.4	65.5
Pullman, Wash.	32.8	—	—	4.4	2.6	39.0	88.0
Lind, Wash.	14.0	—	—	0.0	0.0	13.4	25.0
Tucson, Ariz.	0.8	—	—	0.4	1.2	0.0	77.0
Average	7.1	—	—	5.3	5.6	8.3	67.3

RIO, REG. NO. 275

Rio (C. I. No. 10061) was developed from cooperative experiments between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Oregon Agricultural Experiment Station at the Sherman County Branch Station, Moro, Oreg. Rio is the result of a selection made in 1920 and was entered in the plat experiments at Moro in 1925. It was distributed for commercial growing in 1930. Rio is a smut-resistant variety of hard red winter wheat, being selected from Argentine, C. I. No. 1569, which is a strain of Turkey wheat that has produced high yields at the Moro station.

The comparative data upon which registration is based are shown in Tables 3 and 4.

REX, REG. NO. 276

Rex (C. I. No. 10065), like Rio, was developed in cooperative experiments at the Sherman County Branch Station, Moro, Ore., Supt. D. E. Stephens applying for the registration of both varieties. Rex is the result of a cross between White Odessa (female) and Hard Federation (male) made in 1921. The selection, made in 1926, was first included in nursery experiments in 1929 and in plats in 1930. It was distributed for commercial growing in 1933. Rex is a soft white winter wheat with awnleted spikes and brown glumes. Its superior characters

TABLE 3.—*Annual and average yields of Rio and two other winter wheat varieties at Moro and Pendleton, Oreg.*

Variety	Yield in bushels per acre										Av.	Percentage of Ridit
	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934		
Moro, Oreg., Three 1/20-acre Plats												
Rio (new)..	25.3	28.9	40.7	41.5	15.7	16.4	13.7	12.4	16.7	18.2	23.0	112.7
Kharkof.	27.4	27.0	37.9	40.7	14.4	16.3	15.1	14.5	18.0	18.5	23.0	112.7
Ridit...	25.5	23.5	33.7	34.6	13.9	16.3*	14.5	10.1	17.2	14.2	20.4	100.0
Pendleton, Oreg., 3 Protected 16-foot Rows												
Rio (new)..	—	—	—	—	40.3	34.1	30.5	38.6	41.1	31.8	36.1	114.6
Hybrid 128....	—	—	—	—	36.6	34.6	29.9	34.2	38.4	26.4	33.4	106.0
Ridit...	—	—	—	—	36.6	30.4	29.3	28.8	40.5	23.1	31.5	100.0

*Yield of Kharkof substituted.

TABLE 4.—*Average percentages of smut on Rio,* Rex, and other wheats in uniform bunt nurseries in the western states in the years 1932 to 1934, inclusive.*

Variety	1932, 9 stations	1933, 7 stations	1934, 5 stations	3 years, 21 experiments
Rio (new)...............	6.1	7.1	3.3	5.8
Ridit...................	6.2	12.3	4.4	7.8
Rex (new)...............	14.5	26.4	16.9	19.0
Albit...................	18.8	29.5	20.8	22.8
Kharkof.................	50.1	44.5	56.1	49.7
Hybrid 128..............	72.0	—	85.7	—

*Further information on Rio wheat is given in Oreg. Agr. Exp. Sta. Bul. 308.

are high yield, early maturity, and resistance to lodging, shattering, and smut. The data on smut resistance and yield are shown in Tables 4 and 5, respectively.

THATCHER, REG. NO. 277

Thatcher (Minn. No. 2303, C. I. No. 10003) was developed in cooperative experiments by the Minnesota Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. It is the result of a cross between Marquis x Iumillo (female) and Marquis x Kanred (male) made in 1921 at University Farm, St. Paul, Minn. The selection resulting in Thatcher was made in 1925 and the strain entered the plat experiments in 1929 and the variety was distributed for commercial growing in 1934. Thatcher is an awnleted, hard red spring wheat. Its superior characters are high yields, early maturity, stiff straw, stem rust resistance, and high milling and baking qualities.

The yields upon which registration is based are shown in Table 6.

TABLE 5.—*Annual and average acre yields of Rex and two other winter wheats at Pendleton and Moro, Oreg.*

Station and variety	Yield in bushels per acre						Average	Percentage of Hybrid 128
	1929	1930	1931	1932	1933	1934		
3 Protected 16-foot Rows								
Pendleton:								
Rex (new).....	39.8	45.2	40.1	45.1	43.6	31.2	40.8	121.1
Hybrid 128....	36.6	34.6	32.1	34.2	38.4	26.4	33.7	100.0
Albit.........	32.1	33.9	30.7	38.0	46.2	26.3	34.5	102.4
4 1/53-acre Plats								
Pendleton:								
Rex (new).....	—	—	41.2	41.8	40.2	28.7	38.0	104.4
Hybrid 128....	—	—	37.3	38.4	42.4	27.4	36.4	100.0
Albit.........	—	—	33.9	36.9	39.8	27.4	34.5	94.8
3 Protected 16-foot Rows								
Moro:								
Rex (new).....	—	18.3	11.9	15.9	—	19.0	16.3	103.2
Hybrid 128....	—	16.4	13.5	19.4	—	13.7	15.8	100.0
Albit.........	—	13.7	9.3	10.0	—	14.2	11.8	74.7
3 1/20-acre Plats								
Moro:								
Rex (new).....	—	13.0	17.1	10.2	16.9	22.2	15.9	98.8
Hybrid 128....	—	18.3	11.4	9.2	20.0	21.7	16.1	100.0
Kharkof (C. I. No. 8249)....	—	16.3	15.1	14.5	18.0	18.5	16.5	102.5

TABLE 6.—*Comparative yields of Thatcher and other hard red spring wheats at Crookston and Morris, Minn.**

Variety	Yield in bushels per acre					Average	Percentage of Marquis
	1929	1930	1931	1932	1933		
Crookston							
Thatcher (new)..	33.3	34.4	35.7	19.7	21.7	29.0	119.3
Ceres..........	28.6	31.0	35.2	23.8	23.3	28.4	116.9
Marquis........	20.5	33.0	29.4	18.3	20.3	24.3	100.0
Morris							
Thatcher (new)..	24.2	33.9	26.3	13.6	—	24.5	111.9
Ceres..........	19.7	30.6	24.8	20.6	—	23.9	109.1
Marquis........	19.0	29.5	20.7	18.4	—	21.9	100.0

*For further information on Thatcher wheat see Report of the Fourth Hard Spring Wheat Conference, 1934 (Mimeographed); and The Minn. Seed Grower, 7. Feb. 1934.

STURGEON, REG. NO. 278

Sturgeon (Wis. No. 274, C. I. No. 11703) was produced by the Wisconsin Agricultural Experiment Station (Peninsular Branch) at Sturgeon Bay, Wis. It is the result of a cross between Progress (female) and Marquis (male) made in 1924. The selection resulting in

Sturgeon was made in 1927. It was first included in the plat experiments in 1931 and was distributed for commercial growing in 1934. The breeder, E. J. Delwiche, applied for its registration.

Sturgeon is a high yielding, early maturing, rust-resistant, hard red spring wheat. It is awned and has white glabrous glumes and short hard red kernels resembling Marquis more than Progress. The milling and baking qualities are better than Progress. The comparative data upon which registration is based are shown in Table 7.

TABLE 7.—*Comparative yields and milling and baking data on Sturgeon and other wheats grown at the Peninsular station, Sturgeon Bay, Wis.*

Year	Yield, bu. per acre	Flour yield %	Loaf volume, cu. in.	Water absorption %	Bread per bbl.-lbs.
		Sturgeon (new)			
1931	10.6	70.9	199	63.0	293
1932	10.8	70.0	190	64.1	295
1933	29.3	73.1	181	64.1	295
1934	19.5	—	—	—	—
Average	17.6	71.3	190	63.7	294
Percentage of Marquis	118.9	102.9	97.4	99.7	99.7
		Progress			
1931	6.7	73.5	148	59.9	287
1932	10.7	72.7	116	56.2	280
1933	25.9	71.5	118	58.3	284
1934	19.9	—	—	—	—
Average	15.8	72.6	127	58.1	284
Percentage of Marquis	106.8	104.8	65.1	90.9	96.3
		Marquis			
1931	9.5	69.0	204	63.6	294
1932	10.8	68.0	193	64.1	295
1933	21.5	70.8	189	64.1	295
1934	17.2	—	—	—	—
Average	14.8	69.3	195	63.9	295

BOOK REVIEW

STATISTICAL METHODS FOR RESEARCH WORKERS

By R. A. Fisher. Edinburgh: Oliver & Boyd. Ed. 5. XIII+319 pages and supplementary tables. Illus. 1934. 15/ net.

The first edition of this important work, which has been responsible for a marked change in the methods of analyzing experimental data, appeared in 1925 and contained 239 pages. The fifth edition, published during the last months of 1934, contains 319 pages. Thus in the four last editions there have been added 80 pages of new material in addition to about 10 pages that were rewritten and first appeared in the fourth edition. The fact that five editions have been produced in a little less than 10 years speaks highly of the popularity of the book and shows especially the author's desire to keep each edition up to date by incorporating the latest findings of statistical research applicable to biological investigation.

The differences between the fourth and fifth editions consist of about 12 pages of additional text, two further references to sources, and a continuation of the bibliography of the author's writings since 1931.

No one can justly accuse Dr. Fisher of verbosity in these 12 pages of text for in them he discusses a correction for continuity, gives the exact test of significance for 2 x 2 tables, provides relatively simple adjustments for omitting, without laborious computing, one or more variates from regression equations after they have been included in calculations, and an enlargement of the methods of applying appropriate tests of significance to deviations from regression formulae. In most instances examples of the methods are included. No doubt all of these additions will be welcomed by those investigators who have found the methods given in previous editions of value for interpreting data. (F. Z. H.)

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"THE HUMUS FRONT"

WE are indebted to a reader of the JOURNAL for the following comments and translations on the subject of "humus economy":

"Among the various fronts upon which many European countries are fighting in order to meet the new situations which constantly arise because of growing economic difficulties, the new humus front deserves notice from soil scientists and agronomists.

"A recent issue (No. 16, 1934) of the *Landsberger landwirtschaftliches Nachrichtenblatt*, published by the Prussian Agricultural Experiment Station at Landsberg, carries the following editorial, only a part of which is translated here.

"'HUMUS ECONOMY

"'GERMAN NUTRITION FOR THE GERMAN PEOPLE FROM THE GERMAN SOIL

"'The basis for the reduction of our crop yields, in spite of increasing use of artificial fertilizers, is found only in the increasing lack of humus in our German soils, because the destruction of humus in soil is hastened through the addition of artificial fertilizers, without sufficient provision being made for a proper supplementation of the organic matter. The result of this is that the "old soil force" disappeared. The system of fallowing, which was looked upon as a basis for bringing about abundant plant development and a proper utilization of mineral substances, does not answer the purpose, under these conditions. A healthy humus economy forms the surest basis both for agriculture and animal husbandry. The use of mineral fertilizers promises full benefit only when the soil is sufficiently enriched in humus.'

"The *Deutsche landwirtschaftliche Presse* also devotes an issue (Nov. 10, 1934) to the humus question. Here, the leading article is one by Prof. G. Ruschmann on 'German Nutrition from Its Own Soil, a Question of Healthy Humus Economy.' This is followed by a series of papers by prominent agricultural workers, including Prof. Roemer, Prof. Kappen, and others, dealing with such subjects as 'Assuring Crop Yields by Planned Humus Economy', 'The Artificial Supply of Humus to Soil', 'Organization of German Humus Economy', 'Twelve Commendements for Treatment of Stable Manure', 'The Dry Year of 1934 as a Lesson in Humus', etc.

"The above journal states in an editorial that, because of the importance of these questions for agriculture, it has been decided, beginning January 1, 1935, to publish monthly articles by prominent workers under the general title of 'Soil Fertility and Humus Economy.'"

THE INTERNATIONAL AGRICULTURAL DIRECTORY FOR 1934

THE third edition of the International Section of the Agricultural Directory, edited by J. W. Pincus, has been published by Wm. Grant Wilson of 777 Concord Ave., Cambridge, Mass., and is available at $1 per copy. The directory lists agricultural institutions in 121 countries. An effort has been made to list important agricultural and allied conferences. Also, for the first time, the directory includes a list of national and international organizations doing colonization or other agricultural work.

A FROSTPROOF WHEAT

AT a recent conference of the Scientific-Technical Council of the Commissariat of Soviet Farms in Moscow, Prof. N. V. Tzipin of the Western Siberian Grain Institute reported a successful cross of Agropyron with wheat. In Siberia, there are no varieties of grains that can withstand the cold, and therefore work was started on crossing wheat on the very hardy Agropyron. After four years' experimentation, a hybrid has been obtained which produced 800 wheat grains from one plant and which survived a very severe winter. The plant has many branches or stools and looks like an Agropyron but produces wheat grains.

Prof. Tzipin's report was discussed at some length by plant breeders present and recommendation made to the Commissariat to increase the appropriation for continuing this work, to publish the results in Russian and English, and to send expeditions into western Siberia, the Altai Regions, and Kazakstan and Transcaucasia to make a thorough study of the wild forms of Agropyrons. It was also suggested that a special staff of plant physiologists, geneticists, and phytopathologists should be assigned to this work.

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EFFECTS OF SOIL TYPE AND SOIL TREATMENTS ON THE CHEMICAL COMPOSITION OF ALFALFA PLANTS[1]

A. L. GRIZZARD[2]

IN some portions of the United States, especially in the dairy sections, certain diseases in dairy cattle are associated with mineral deficiencies, particularly phosphorus, in the roughage fed. As these cattle diseases have been observed in Michigan, information concerning the calcium and phosphorus content of alfalfa hay grown in that state on different soils and with various fertilizer treatments was desired in order to determine under what soil conditions deficiencies in the mineral content of alfalfa hay would be found. The protein content of alfalfa is also important from a feeding standpoint. Accordingly, this investigation was undertaken to determine the composition of alfalfa grown on several of the most extensive soil types of the state and to study the effect of limestone and of phosphate and potash fertilizers on the nitrogen, calcium, and phosphorus content of alfalfa grown on these soil types.

REVIEW OF LITERATURE

A great amount of work has been done on the quality of crops as affected by fertilizer treatments and soil conditions. Of the papers reviewed, only those which deal directly with this problem are mentioned. A fairly complete review of the literature may be obtained from the references given.

Alway (1)[3], using clover and alfalfa; Mather (7), working with alfalfa, timothy, and alsike; Sewell and Latshaw (17); Nygard (11) and others at the Montana station (9); Ames and Boltz (2); Eckles and co-workers (3); and Pitman (12), working with alfalfa, found that applications of available phosphorus to phosphorus-deficient soils increased the percentage of the element in the plants.

[1]Contribution from the Soils Department, Michigan State College, East Lansing, Mich. Abstract of a thesis submitted to the Graduate School of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with permission of the Director of the Michigan Agricultural Experiment Station as Journal Article 194 n.s. of the Experiment Station. Received for publication November 8, 1934.

[2]Formerly Assistant in Soils, Michigan State College; now Assistant Agronomist, Virginia Agricultural Experiment Station, Blacksburg, Va. The writer expresses his thanks and appreciation to Dr. C. E. Millar and Dr. C. H. Spurway of the Soils Department of Michigan State College for their kind advice and constructive criticism given during the course of the investigation and in the preparation of this paper.

[3]Figures in parenthesis refer to "Literature Cited," p. 99.

McCool and Weldon (8) found that the amounts of phosphorus and potassium in the sap of red clover grown on muck soil in pots was roughly proportional to the amounts of these constituents in the fertilizers applied.

Fonder (4) reported that the calcium content increased with maturity of the alfalfa plant. Also, the calcium content was considerably higher in the leaves than in the stems. Of the soils studied, those of medium texture produced alfalfa of higher calcium content than did the very light or the heavy soils.

Holtz (5) found the calcium content of red clover to be largely influenced by the calcium content of the soil. The phosphorus content of red clover also correlated closely with the available phosphorus content of the soil.

Ames and Boltz (2) report that additions of calcium and magnesium to the soil in the form of limestone increased the calcium and magnesium content of the alfalfa, but decreased the yield. The percentages of nitrogen, phosphorus, potassium, and calcium were higher in the first cutting of alfalfa, where the yields were larger than in the second cutting.

Acre application of hydrated lime up to 2,000 pounds increased the calcium content of alfalfa, while the potassium content was decreased by applications up to 8,000 pounds, according to Sewell, *et al.* (16). Heavier additions of lime increased the potassium in the plants. Lime application decreased the nitrogen content of alfalfa, while phosphate treatments reduced the percentage of nitrogen, calcium, phosphorus, and potassium.

Reimer and Tartar (13) and Neidig and co-workers (10) report that application of sulfur increased the nitrogen content of alfalfa.

Satala (14) found that alfalfa hay cut in the one-half bloom stage contained more calcium than plants cut at the one-fourth or three-fourth bloom stage. The calcium content of alfalfa decreased with the number of cuttings and was higher in the first cutting than in the second, which, in turn, contained a higher calcium content than alfalfa cut the third time.

EXPERIMENTAL METHODS

The investigation was carried on under both field conditions and in the greenhouse. For the field studies, use was made of the experimental plats in soil fertility conducted by the Soils Section of the Michigan Experiment Station in different sections of the state. The fertilizer was applied in some cases to established stands of alfalfa as a topdressing, while in other instances the fertilizer and lime were applied and worked into the soil before seeding the alfalfa. One or two cuttings only were obtained from some fields before the farmer plowed down the alfalfa in order to continue his system of crop rotation. In other cases several cuttings of alfalfa were taken.

The pot experiments in the greenhouse were conducted in order that the effect of soil treatments on the composition of the alfalfa might be measured under more controlled conditions than pertain in the field.

Another phase of the problem was the comparison of the composition of alfalfa samples taken from 2 selected areas in field plats with the composition of samples taken from 12 areas geometrically located on each plat.

METHOD OF FIELD SAMPLING

In the selection sampling method the entire plat was carefully observed for variations in the plant growth and uniformity of stand, and samples were then taken from two ½ square rod areas decided upon by two persons as representative

of plant growth on the plat. Several handfuls of green plants from each area were combined to make a standard sample from the plat. All samples were placed in paper containers and taken to a large laboratory where they were spread out to dry for 6 weeks.

Alfalfa samples taken in 1930 and 1931 were carefully separated into stems and leaves and the weight of each determined before analyzing.

The moisture, total nitrogen, calcium oxide, and phosphorus pentoxide contents of the alfalfa plants were determined according to the methods outlined in the second edition of the Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists. All analyses were made in duplicate and all results are reported on the oven-dry basis.

The data are presented under the name of each soil type on which studies were conducted. A description of each soil may be obtained from soil survey reports for Michigan.

RESULTS OF FIELD EXPERIMENTS

ISABELLA SANDY LOAM

The acidity of the soil was corrected sufficiently for the growing of alfalfa by the application of 3 tons of limestone to the acre in early June, after the soil had been plowed and worked down. Phosphate and potash fertilizers were drilled about 5 inches deep in the soil the last week in July. Due to deficiency of soil moisture, the alfalfa was not seeded until the first week in August, 1929. A good stand of alfalfa was obtained which produced better than an average crop. The effects of the various soil treatments on the composition of the alfalfa and the ratio of leaves to stems are shown by the data in Tables 1, 2, 3, 4, and 5.

The data in Tables 1 to 5, inclusive, show that the effects of soil treatments on the composition of alfalfa are not entirely consistent for different cuttings and in different seasons. Evidently, factors other than those studied play a great part in determining the chemical composition and ratio of leaves to stems of alfalfa plants. The data, however, warrant the following observations:

1. When taken in the one-half bloom stage, the first cuttings showed a much lower ratio of leaves to stems than the second cuttings. Also, the first cutting in the bud stage was much more leafy than when taken in the one-half bloom stage. The ratio of leaves to stems was not consistently affected by soil treatments. No explanation is offered for the very low ratio of leaves to stems found in the first cutting for 1931.

2. Averages for group treatments show that the nitrogen content of the leaves was approximately double that of the stems in most cases and considerably more than double for the first cutting in 1931. All soil treatments containing limestone tended to increase the nitrogen content of both leaves and stems of alfalfa, as compared to that of alfalfa grown on untreated soil. The increases in nitrogen content were least consistent in the results for the first cutting in 1931. In some instances, increasing quantities of limestone applied tended to increase nitrogen content of the alfalfa.

3. The data as a whole showed the calcium content of alfalfa leaves to be from two to three times as great as that of the stems. Applica-

TABLE 1.—*Effect of increasing limestone applications with superphosphate and muriate of potash to Isabella sandy loam soil on the partial composition of alfalfa cut in the bud stage in 1930.**

Plat No.	Limestone, lbs.	Ratio of leaves to stems	Percentage of Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	Limestone Alone									
1	None	1.46	10.2	9.5	1.43	2.81	2.03	4.75	0.74	0.82
2	552	1.36	11.1	10.0	1.54	2.81	1.83	4.86	0.76	0.82
3	2,000	1.46	10.8	10.0	1.72	3.08	1.83	4.30	0.68	0.79
4	6,000	1.72	12.4	10.6	1.86	3.47	2.03	5.16	0.60	0.84
5	12,500	1.43	11.8	10.9	2.22	4.04	1.99	5.28	0.69	0.86
	390 lbs. 20% Superphosphate									
6	None	1.43	11.2	10.4	1.56	2.68	2.03	5.22	0.74	0.79
7	552	1.35	9.8	10.2	1.55	2.84	1.97	5.09	0.72	0.78
8	2,000	1.44	9.8	9.3	1.53	2.92	2.04	4.65	0.74	0.83
9	6,000	1.43	9.4	9.3	1.86	3.26	1.93	4.71	0.70	0.83
10	12,500	1.48	10.9	10.1	2.17	3.82	1.76	5.49	0.60	0.73
	186 lbs. Muriate of Potash									
11	None	1.43	9.9	11.8	1.59	2.45	1.65	3.81	0.57	0.61
12	552	1.20	9.9	10.8	1.69	2.81	1.81	4.14	0.53	0.71
13	2,000	1.30	10.0	12.7	1.89	3.60	1.39	3.40	0.60	0.61
14	6,000	1.17	10.4	9.5	1.70	2.55	1.65	4.29	0.64	0.60
15	12,500	1.54	10.7	9.9	2.14	3.94	1.23	3.47	0.50	0.67
	234 lbs. 20% Superphosphate and 94 lbs. Muriate of Potash, or 390 lbs. 0–12–12 Fertilizer									
16	None	1.25	13.2	11.3	1.55	2.84	1.72	3.61	0.80	0.85
17	552	1.31	13.9	11.8	1.69	3.99	1.64	3.77	0.72	0.81
18	2,000	1.54	13.2	12.3	2.07	4.14	1.57	3.62	0.64	0.88
19	6,000	1.38	12.4	12.8	1.61	3.16	1.71	4.41	0.64	0.78
20	12,500	1.19	12.8	13.0	1.91	3.51	1.63	4.78	0.55	0.66
	Averages									
No limestone		1.39	11.1	10.8	1.53	2.69	1.86	4.35	0.71	0.77
Limestone alone		1.49	11.5	10.4	1.84	3.35	1.92	3.90	0.68	0.83
Limestone+phosphorus		1.42	9.9	9.7	1.78	3.21	1.92	4.99	0.69	0.79
Limestone+potash		1 30	10.7	10.8	1.86	3.23	1.52	3.83	0.57	0.65
Limestone + phosphorus and potash		1.35	13.1	12.5	1.82	3.70	1.64	4.14	0.64	0.78

*Results reported on oven-dry basis.

TABLE 2.—*Effect of increasing limestone applications with superphosphate and muriate of potash to Isabella sandy loam soil on the partial composition of alfalfa, first cutting for hay, one half-bloom stage, 1930.**

Plat No.	Limestone, lbs.	Ratio of leaves to stems	Percentage of Water, Stems	Water, Leaves	N, Stems	N, Leaves	CaO, Stems	CaO, Leaves	P_2O_5, Stems	P_2O_5, Leaves
	Limestone Alone									
1	None	0.94	8.3	10.3	1.35	2.26	2.57	7.11	0.97	0.90
2	552	0.95	8.5	10.6	1.49	2.95	2.07	6.29	0.66	0.85
3	2,000	0.95	8.9	10.7	1.54	2.87	2.19	6.77	0.79	1.03
4	6,000	0.99	8.6	11.1	1.79	3.34	1.92	5.78	0.83	1.03
5	12,500	1.21	9.6	11.5	1.96	3.50	2.04	6.11	0.59	0.88
	390 lbs. 20% Superphosphate									
6	None	0.88	9.1	10.1	1.16	2.32	2.43	6.61	0.93	1.00
7	552	1.09	9.2	10.0	1.63	3.12	2.09	6.37	0.63	0.88
8	2,000	0.93	9.4	9.6	1.47	3.18	1.88	6.54	0.88	1.00
9	6,000	1.07	10.0	10.9	1.84	3.56	1.94	5.92	0.59	0.88
10	12,500	0.81	8.4	10.3	1.55	3.03	1.81	5.59	0.62	0.84
	186 lbs. Muriate of Potash									
11	None	0.83	9.5	10.9	1.18	2.35	2.12	5.51	0.96	1.01
12	552	0.88	9.4	10.3	1.59	2.90	2.05	5.37	0.67	0.79
13	2,000	1.01	10.0	10.4	1.75	3.22	1.67	4.20	0.63	0.74
14	6,000	0.83	9.0	10.4	1.54	3.23	1.58	4.06	0.53	0.72
15	12,500	1.12	9.1	10.2	1.71	3.37	1.71	4.64	0.36	0.59
	234 lbs. 20% Superphosphate and 94 lbs. Muriate of Potash, or 390 lbs. 0–12–12 Fertilizer									
16	None	0.90	9.6	10.5	1.55	2.39	2.24	6.09	0.92	1.00
17	552	1.05	9.2	10.5	1.27	3.27	1.98	5.68	0.48	0.74
18	2,000	0.93	9.0	11.5	1.31	2.78	1.93	5.65	0.68	0.80
19	6,000	1.06	9.4	11.1	1.57	3.37	1.74	4.83	0.62	0.76
20	12,500	1.01	9.6	12.1	1.60	3.34	1.91	5.26	0.49	0.69
	Averages									
	No limestone	0.89	9.1	10.4	1.31	2.33	2.34	6.33	0.95	0.98
	Limestone alone	1.03	8.9	10.9	1.69	3.15	2.06	6.24	0.72	0.95
	Limestone + phosphorus	0.97	9.3	10.2	1.62	3.22	1.93	6.11	0.68	0.90
	Limestone+potash	0.96	9.4	10.3	1.64	3.18	1.75	4.57	0.55	0.71
	Limestone + phosphorus and potash	1.01	9.3	11.3	1.44	3.19	1.89	5.36	0.57	0.75

*Results reported on oven-dry basis.

TABLE 3.—*Effect of increasing limestone applications with superphosphate and muriate of potash to Isabella sandy loam soil on the partial composition of alfalfa, second cutting for hay, one half-bloom stage, 1930.**

Plat No.	Limestone, lbs.	Ratio of leaves to stems	Percentage of Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	Limestone Alone									
1	None	1.21	11.2	11.1	1.72	3.25	2.14	4.44	0.91	0.94
2	552	1.67	11.5	11.4	1.95	3.93	1.89	3.98	0.71	0.77
3	2,000	1.51	11.6	12.9	1.87	3.68	2.02	4.26	0.68	0.79
4	6,000	1.59	12.4	12.5	2.06	4.00	2.09	4.36	0.67	0.75
5	12,500	1.66	12.1	12.8	2.03	4.06	2.13	4.38	0.66	0.69
	390 lbs. 20% Superphosphate									
6	None	1.73	9.6	12.2	1.76	3.65	2.03	4.00	0.92	1.09
7	552	1.68	10.4	12.0	2.06	3.88	2.37	4.90	0.72	0.83
8	2,000	1.61	10.8	10.5	2.32	4.14	2.21	3.93	0.68	0.81
9	6,000	1.71	11.0	11.5	2.06	4.02	2.32	3.85	0.73	0.75
10	12,500	2.03	11.0	11.0	2.06	4.08	2.06	6.66	0.53	0.70
	186 lbs. Muriate of Potash									
11	None	1.15	9.7	11.5	1.77	2.94	2.12	4.87	0.94	1.09
12	552	1.47	10.8	12.0	1.87	3.81	1.86	3.77	0.65	0.76
13	2,000	1.39	11.0	12.1	1.96	3.50	2.14	4.41	0.65	0.71
14	6,000	1.81	11.2	12.8	2.16	4.01	1.67	3.65	0.70	0.79
15	12,500	1.77	11.4	11.9	2.15	4.11	2.24	4.02	0.53	0.68
	234 lbs. 20% Superphosphate and 94 lbs. Muriate of Potash, or 390 lbs. 0–12–12 Fertilizer									
16	None	1.38	11.4	11.3	1.98	3.30	2.25	4.42	0.88	0.95
17	552	1.56	11.4	11.9	1.97	3.88	2.18	4.20	0.67	0.75
18	2,000	1.56	11.5	11.0	1.87	3.53	2.15	4.30	0.57	0.64
19	6,000	1.69	12.0	10.9	2.10	3.94	2.05	4.12	0.63	0.76
20	12,500	1.54	10.9	11.6	2.13	3.69	2.18	4.84	0.51	0.66
	Averages									
No limestone		1.28	10.5	11.5	1.81	3.29	2.14	4.43	0.91	1.02
Limestone alone		1.61	11.9	12.2	1.98	3.92	2.03	4.25	0.68	0.75
Limes.....tone+phosphorus		1.76	10.8	11.3	2.13	4.03	2.24	4.84	0.67	0.77
Limestone+potash		1.61	11.1	12.2	2.04	3.86	1.98	3.96	0.63	0.74
Limestone + phosphorus and potash		1.59	11.5	11.4	2.02	3.76	2.14	4.37	0.59	0.70

*Results reported on oven-dry basis.

TABLE 4.—*Effect of increasing limestone applications with superphosphate and muriate of potash to Isabella sandy loam soil on the partial composition of alfalfa, first cutting for hay, one half-bloom stage, 1931.**

Plat No.	Limestone, lbs.	Ratio of leaves to stems	Percentage of Water: Stems	Water: Leaves	N: Stems	N: Leaves	CaO: Stems	CaO: Leaves	P_2O_5: Stems	P_2O_5: Leaves
	Limestone Alone									
1	None	0.81	5.7	6.8	1.55	3.41	1.79	3.65	0.72	1.00
2	552	0.64	5.7	7.2	1.81	3.91	1.50	4.34	0.35	0.74
3	2,000	0.69	5.8	7.5	1.62	3.71	1.48	4.27	0.66	0.81
4	6,000	0.67	6.6	8.6	1.69	4.05	1.61	4.90	0.40	0.84
5	12,500	0.57	6.5	8.2	1.74	4.00	1.59	4.16	0.41	0.85
	390 lbs. 20% Superphosphate									
6	None	0.65	6.5	8.2	1.57	3.75	1.73	3.35	0.50	0.84
7	552	0.64	6.2	8.4	1.50	3.54	1.58	4.62	0.45	0.78
8	2,000	0.64	6.1	8.2	1.66	3.85	1.45	4.59	0.51	0.80
9	6,000	0.89	6.5	8.4	1.90	4.15	1.70	4.49	0.51	0.86
10	12,500	0.64	6.6	8.6	1.87	3.97	1.51	4.71	0.49	0.85
	186 lbs. Muriate of Potash									
11	None	0.72	6.4	7.8	1.49	3.24	1.53	3.46	0.75	1.02
12	552	0.56	6.1	7.6	1.64	4.03	1.44	3.46	0.36	0.74
13	2,000	0.55	6.2	7.9	1.42	3.51	1.53	3.77	0.34	0.73
14	6,000	0.55	6.2	7.9	1.53	3.89	1.23	3.96	0.37	0.77
15	12,500	0.59	6.1	8.1	1.82	3.83	1.29	4.35	0.39	0.72
	234 lbs. 20% Superphosphate and 94 lbs. Muriate of Potash, or 390 lbs. of 0-12-12 Fertilizer									
16	None	0.63	6.5	7.8	1.41	3.75	1.37	3.27	0.55	0.99
17	552	0.76	6.8	8.2	1.58	3.87	1.52	4.03	0.37	0.77
18	2,000	0.68	6.6	8.3	1.59	3.66	1.37	4.40	0.35	0.69
19	6,000	0.52	6.5	8.3	1.59	4.00	1.19	4.33	0.40	0.77
20	12,500	0.61	6.5	8.0	1.76	4.06	1.24	3.62	0.42	0.77
	Averages									
	No limestone	0.70	6.3	7.6	1.51	3.54	1.61	3.18	0.63	0.99
	Limestone alone	0.64	6.2	7.9	1.72	3.92	1.55	4.43	0.46	0.81
	Limestone+phosphorus	0.70	6.3	8.4	1.73	3.88	1.56	4.60	0.49	0.82
	Limestone+potash	0.56	6.2	7.9	1.60	3.82	1.37	3.89	0.37	0.74
	Limestone + phosphorus and potash	0.64	6.6	8.2	1.63	3.89	1.33	4.09	0.39	0.75

*Results reported on oven-dry basis.

TABLE 5.—*Effect of increasing limestone applications with superphosphate and muriate of potash to Isabella sandy loam soil on the partial composition of alfalfa, second cutting for hay, one half-bloom stage, 1931.**

Plat No.	Limestone, lbs.	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	Limestone Alone									
1	None	1.53	8.2	9.9	1.71	3.29	1.77	3.56	0.54	0.59
2	552	1.87	8.6	10.1	1.95	3.78	1.79	3.69	0.36	0.59
3	2,000	1.24	8.0	10.2	2.01	4.11	1.59	4.07	0.37	0.60
4	6,000	1.60	8.0	10.5	2.38	4.22	1.55	3.69	0.39	0.59
5	12,500	1.36	10.5	13.8	1.95	4.03	1.52	4.08	0.37	0.62
	390 lbs. 20% Superphosphate									
6	None	1.34	9.7	11.7	1.80	3.88	1.52	3.59	0.42	0.64
7	552	1.61	9.8	11.9	2.20	4.17	1.79	4.08	0.49	0.65
8	2,000	1.25	10.6	12.5	2.07	4.37	1.49	4.15	0.43	0.64
9	6,000	1.25	10.4	13.8	2.05	4.05	1.67	4.27	0.40	0.60
10	12,500	1.14	11.0	14.0	2.09	4.35	1.44	3.79	0.49	0.72
	186 lbs. Muriate of Potash									
11	None	1.54	9.9	11.2	1.98	3.70	1.66	3.33	0.64	0.70
12	552	1.55	9.3	11.0	2.02	3.98	1.78	3.63	0.42	0.61
13	2,000	1.22	9.3	11.2	2.09	4.01	1.51	3.89	0.39	0.59
14	6,000	1.74	9.9	12.7	2.06	4.19	1.33	3.28	0.43	0.54
15	12,500	1.46	8.9	11.5	2.10	4.11	1.41	3.33	0.42	0.63
	234 lbs. 20% Superphosphate and 94 lbs Muriate of Potash, or 390 lbs. 0–12–12 Fertilizer									
16	None	1.66	7.8	8.7	1.81	3.35	1.93	3.53	0.50	0.57
17	552	1.65	8.9	8.9	1.84	3.90	1.57	3.57	0.39	0.57
18	2,000	1.55	7.6	9.3	2.00	4.02	1.16	2.77	0.38	0.57
19	6,000	1.48	7.9	10.1	2.06	3.88	1.52	3.27	0.40	0.61
20	12,500	1.26	9.4	10.0	2.15	4.16	1.32	2.80	0.39	0.61
	Averages									
	No limestone	1.52	8.9	10.4	1.83	3.56	1.72	3.50	0.53	0.63
	Limestone alone	1.52	8.8	11.2	2.07	4.04	1.61	3.88	0.37	0.60
	Limestone+phosphorus	1.31	10.5	13.1	2.10	4.24	1.60	4.07	0.45	0.65
	Limestone+potash	1.49	9.4	11.6	2.07	4.07	1.51	3.53	0.42	0.59
	Limestone + phosphorus and potash	1.49	8.5	9.6	2.01	3.99	1.39	3.10	0.39	0.59

*Results reported on oven-dry basis.

tion of limestone alone did not consistently increase or decrease the calcium content of the alfalfa, nor did increasing quantities of limestone alone or with fertilizer. Applications of potash with limestone tended to decrease the calcium content of the plants.

4. Group treatment averages of the data show that alfalfa leaves contained a higher phosphorus content than did the stems. Applications of limestone alone tended to depress the phosphorus content of the plants. Either potash or phosphorus applied with limestone had a depressing effect on the phosphorus content of both stems and leaves of the alfalfa. The phosphorus content of the stems and leaves tended to be higher in the first cutting than in the second cutting. Applications of phosphorus alone or in combination did not increase the phosphorus content of the alfalfa.

BROOKSTON SOILS

These soils do not require liming for alfalfa growing. The crops usually grown respond favorably to applications of superphosphate oı fertilizers containing a high percentage of phosphoric acid.

Brookston silt loam.—On field 1 the alfalfa was seeded with oats in the spring of 1929 and the fertilizer was applied broadcast on the surface of the soil after the second cutting in the season of 1930, without harrowing to work the fertilizer into the soil. The alfalfa on field 2 was several years old. The fertilizer was applied as a topdressing after the second cutting in the season of 1930. Samples were taken from both fields in 1931. The data are presented in Table 6.

Brookston clay loam.—The alfalfa grown on this soil was seeded in wheat in the spring of 1929 and topdressed after the first cutting for hay in the season of 1930. Samples taken for analytical work were obtained in 1931. The data are presented in Table 7.

Brookston loam.—The field was prepared after corn for the seeding of wheat in which the alfalfa was seeded the spring of 1930. The data are given in Table 8.

The data in Tables 6, 7, and 8 show that the first cutting of alfalfa grown on Brookston soils had a much lower ratio of leaves to stems than the second cutting. This result is in agreement with that from Isabella sandy loam. With one exception, fertilizer treatments decreased the ratio of leaves to stems on Brookston clay loam, but increased it in the second cutting on Brookston loam.

The nitrogen content of the alfalfa leaves was approximately double that of the stems. The effect of fertilizer applications on nitrogen content of both leaves and stems was inconsistent.

For all treatments the calcium content of the leaves was from two to three times that of the stems. No consistent variation in the calcium content of the alfalfa was observed as a result of fertilization.

On the whole, fertilization increased the phosphorus content of the alfalfa, although there are several cases where this result was not found.

MIAMI SILT LOAM

Miami silt loam is of medium fertility and alfalfa growing on this soil usually responds well to applications of fertilizer containing a high percentage of phosphoric acid and a moderate percentage of potash.

TABLE 6.—*Effect of various fertilizer applications to Brookston silt loam soil on the partial composition of alfalfa, cut in the one-half bloom stage, 1931.**

Plat No.	Treatment	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
			First Cutting, Field 1							
1	None	0.59	8.2	10.9	1.70	3.88	1.51	6.49	0.30	0.57
2	250 lbs. 0–20–20	0.63	7.9	10.0	1.91	3.96	1.52	5.61	0.41	0.57
3	500 lbs 0–20–20	0.59	9.8	10.0	2.20	4.02	1.42	5.64	0.50	0.55
4	500 lbs. 0–0–20	0.51	7.5	10.1	1.84	3.94	1.47	5.50	0.30	0.52
5	500 lbs. 0–20–0	0.55	7.2	9.9	2.16	4.00	1.30	5.30	0.57	0.67
			Second Cutting, Field 1							
1	None	1.26	11.0	11.2	1.86	3.46	1.95	4.32	0.40	0.42
2	250 lbs. 0–20–20	1.28	11.6	12.3	1.87	3.88	1.99	5.12	0.41	0.51
3	500 lbs. 0–20–20	1.27	11.5	12.0	1.86	3.84	1.90	4.86	0.57	0.56
4	500 lbs. 0–0–20	1.29	11.1	11.4	1.88	4.05	1.98	4.95	0.39	0.53
5	500 lbs. 0–20–0	1.26	11.3	10.6	1.86	3.99	1.99	4.97	0.59	0.60
			First Cutting, Field 2							
6	None	0.64	8.2	10.2	2.08	3.89	1.57	5.15	0.37	0.57
7	300 lbs. 0–16–0	0.83	8.7	10.3	2.14	3.94	1.47	4.42	0.38	0.56
8	300 lbs. 0–16–8	0.75	8.1	10.1	2.07	4.18	1.61	5.63	0.38	0.62
			Second Cutting, Field 2							
6	None	1.39	7.7	10.4	1.96	4.07	1.99	4.98	0.37	0.58
7	300 lbs. 0–16–0	1.19	7.7	9.8	1.89	4.15	1.80	4.39	0.30	0.49
8	300 lbs. 0–16–8	1.30	7.7	10.2	2.19	4.11	1.85	5.03	0.33	0.53

*Results reported on oven-dry basis.

TABLE 7.—*Effect of various fertilizer applications to Brookston clay loam soil on the partial composition of alfalfa cut in the one-half bloom stage, second cutting for hay, 1931.**

Plat No.	Treatment	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
1	None	1.75	7.1	8.4	2.26	4.47	1.83	4.90	0.30	0.58
2	300 lbs. 0-20-0	1.84	7.3	8.3	2.47	4.45	1.90	4.75	0.47	0.65
3	500 lbs. 0-20-0	1.35	6.7	8.1	2.41	4.66	1.68	4.28	0.46	0.70
4	300 lbs. 0-20-20	1.56	8.0	10.9	2.18	4.37	1.79	5.12	0.33	0.66
5	500 lbs. 0-20-20	1.28	7.7	10.6	2.21	3.43	1.61	4.74	0.40	0.63

*Results reported on oven-dry basis.

TABLE 8.—*Effect of various fertilizer applications to Brookston loam soil on the partial composition of alfalfa cut in the one-half bloom stage for hay in 1931.**

Plat No.	Treatment	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
	First Cutting									
1	None	0.66	6.2	7.4	1.59	4.20	1.69	4.45	0.23	0.55
2	500 lbs. 0-16-0	0.64	6.3	7.7	1.78	4.28	1.75	5.04	0.37	0.64
3	500 lbs. 0-16-20	0.52	6.4	7.5	1.76	3.61	1.50	4.48	0.32	0.61
	Second Cutting									
1	None	1.03	6.3	7.6	1.86	4.01	2.22	5.30	0.35	0.50
2	500 lbs. 0-16-0	1.32	7.1	8.5	2.15	4.11	2.25	5.43	0.39	0.50
3	500 lbs. 0-16-20	1.76	7.3	7.9	2.19	4.13	2.28	4.85	0.37	0.50

*Results reported on oven-dry basis

In the late spring of 1929, corn stubble was plowed down and a good seedbed for alfalfa prepared. The fertilizer was placed on the soil surface with a broadcasting machine and worked well into the soil during the seedbed preparation. A good stand of alfalfa was obtained, the yields being considerably influenced by fertilizer treatments. Samples of the second cutting only were taken for analysis. The data are presented in Table 9.

Table 9 shows that on Miami silt loam fertilizer treatments depressed the ratio of leaves to stems and increased somewhat the nitrogen content of alfalfa stems and leaves over that of plants from the no-treatment plats.

The treatment that contained potash markedly depressed the calcium content of alfalfa stems and leaves compared to that of alfalfa which received no treatment. The calcium content of the leaves was double that of the stems.

Alfalfa leaves contained a higher phosphorus content than the stems in all cases. The phosphate plus potash treatment increased the phosphorus content of both stems and leaves over that of plants from the untreated soil.

GILFORD LOAM

The plow soil of this soil type is nearly neutral in reaction and the lower subsoil and substrata are highly calcareous. Fertilizers rich in phosphoric acid are beneficial to most crops. The field from which the samples of alfalfa were taken for analysis had been in alfalfa for several years. Fertilizer was applied as a topdressing by means of the fertilizer attachment on a grain drill and it was not worked into the soil. The results are shown in Table 10.

The data presented in Table 10 show that all soil treatments depressed the ratio of alfalfa leaves to stems as compared to that for plants from unfertilized soil.

Taking the nitrogen content of stems and leaves of alfalfa from unfertilized soil as a basis, the phosphate treatment increased the nitrogen content of both stems and leaves; while the phosphate plus potash treatment depressed it somewhat in both the stems and leaves.

Fertilizer lowered the calcium content of stems and leaves, the treatment that contained potash having the greatest depressing effect. The calcium content of the leaves was nearly three times that of the stems.

The phosphorus content of leaves was higher than that of the stems. Both fertilizer treatments increased the phosphorus content of stems and leaves.

EFFECT OF SOIL TYPE BOTH WITH AND WITHOUT LIME AND FERTILIZER TREATMENTS ON THE PARTIAL COMPOSITION OF ALFALFA

Data for all cuttings of alfalfa taken from each soil type and for all fertilizer and lime treatments were averaged to determine what differences might be found in the nitrogen, calcium, and phosphorus

TABLE 9.—*Effect of various fertilizer applications to Miami silt loam soil on the partial composition of alfalfa cut in the one-half bloom stage, second cutting for hay, 1930.**

Plat No.	Treatment	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
1	None	2.05	11.9	10.9	1.98	3.97	2.08	5.32	0.28	0.46
2	300 lbs. 0-16-0	1.48	10.9	13.7	2.02	4.15	2.01	5.41	0.29	0.50
3	300 lbs. 0-16-8	1.61	11.9	13.5	2.11	4.21	1.86	3.38	0.34	0.53

*Results reported on oven-dry basis.

TABLE 10.—*Effect of various fertilizer applications to Gilford loam soil on the partial composition of alfalfa cut in the one-half bloom stage, first cutting for hay, 1931.**

Plat No.	Treatment	Ratio of leaves to stems	Percentage of							
			Water		N		CaO		P_2O_5	
			Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves
1	None	1.26	8.4	11.0	2.05	3.57	2.28	7.56	0.26	0.38
2	300 lbs. 0-16-0	0.97	8.3	10.8	2.15	3.78	2.11	7.43	0.38	0.58
3	300 lbs. 0-16-8	0.93	8.0	11.2	1.99	3.64	1.78	7.00	0.38	0.59

*Results reported on oven-dry basis.

content of plants grown on the various soil types. These data are presented in Table 11.

TABLE 11.—*Partial composition of alfalfa grown on different soil types, averaging results for all cuttings from plats receiving various soil treatments.*

Soil type	Percentage of N		Percentage of CaO		Percentage of P_2O_5	
	Stems	Leaves	Stems	Leaves	Stems	Leaves
Brookston silt loam	1.99	4.01	1.69	5.11	0.42	0.55
Brookston clay loam	2.32	4.12	1.75	4.72	0.42	0.66
Brookston loam	1.97	4.04	1.95	4.95	0.36	0.56
Miami silt loam	2.12	4.18	1.94	4.40	0.32	0.52
Gilford loam	2.07	3.71	1.95	7.22	0.38	0.59
Isabella sandy loam	1.80	3.59	1.77	4.43	0.57	0.77
Average	2.05	3.94	1.84	5.14	0.41	0.61

In Table 12 is given the average composition of alfalfa grown on the different soil types without treatments of lime or fertilizer.

TABLE 12.—*Partial composition of alfalfa grown on different soil types, averaging results for all cuttings from plats receiving no lime or fertilizer treatment.*

Soil type	Percentage of N		Percentage of CaO		Percentage of P_2O_5	
	Stems	Leaves	Stems	Leaves	Stems	Leaves
Brookston silt loam	1.90	3.82	1.75	5.23	0.36	0.53
Brookston clay loam	2.26	4.47	1.83	4.90	0.30	0.58
Brookston loam	1.73	4.11	1.95	4.93	0.29	0.53
Miami silt loam	1.98	3.97	2.08	5.32	0.28	0.46
Gilford loam	2.05	3.37	2.28	7.56	0.26	0.38
Isabella sandy loam	1.59	3.08	1.93	4.36	0.75	0.88
Average	1.92	3.80	1.97	5.38	0.37	0.56

The data in Tables 11 and 12 indicate that the heavy soil types, such as Brookston clay loam, tend to give a higher nitrogen content in the alfalfa plants than the lighter soil types, such as Isabella sandy loam, both when fertilized and unfertilized. On the other hand, the lighter soil types tend to give a decidedly higher phosphorus content in the alfalfa plants than the heavy soil types, this being true both in the fertilized and in the unfertilized condition. In the case of calcium, there is a tendency for this element to be decidedly higher in the intermediate soil types, such as the Gilford and Brookston loams, than in either the heavy or light soil types. Apparently, these data indicate that soil type predominates over fertilizer treatments in the composition of alfalfa; although fertilization tends to influence the composition of alfalfa, especially in certain soils.

GENERAL DISCUSSION

A comparison of the analysis of alfalfa cuttings with regard to the ratio of leaves to stems shows that, on the whole, the data are quite inconsistent. It cannot be said that limestone or fertilizer treatments increased or decreased to any appreciable extent the ratio of leaves to stems of alfalfa plants taken from the various soil types under investigation.

Average data (Tables 11 and 12) show that soil treatments tended to increase the total nitrogen content of alfalfa grown on the soil types under investigation and also the phosphorus content, with the exception of the alfalfa grown on Isabella sandy loam in which case a depression of phosphorus content resulted. The data for individual soil types, however, show considerable inconsistency in this regard.

General averages of data indicate that soil treatments decreased the calcium content of the alfalfa. Data are variable, however, for individual soil types, with the exception of that for Gilford loam. Treatments including potash showed a decided tendency to reduce the calcium content of alfalfa on all soils except the Brookston type.

In Tables 11 and 12 it is shown that the heaviest textured soils produced alfalfa containing a higher total nitrogen content with a medium calcium and phosphorus content. Such hays are considered to have an unfavorable balance of digestible nutrients and were produced in regions where nutritional disorders in dairy cattle are known to exist. Alfalfa grown on medium textured soils, such as the Brookston and Gilford loams, was generally high in total calcium, medium in nitrogen, and low in phosphorus. The low phosphorus content of the hay gives an unfavorable nutrient balance. These soils are of widest occurrence in regions where nutritional disorders in cattle are known to occur. On the lighter textured soil, however, such as Isabella sandy loam and Fox sandy loam (Table 13), the phosphorus content of the alfalfa hay is high in comparison with nitrogen and calcium. This condition gives a hay with better nutritive balance. These soils occur in regions where nutritional disorders in dairy cattle are not commonly observed. It appears, therefore, that soil type is an important factor in determining the feeding value of alfalfa hay, and indirectly, the location and extent of nutritional disturbances in dairy cattle.

SYSTEMATIC SAMPLING STUDY

In 1932, a comparative study was made of the random method of sampling previously described with a systematic method of taking samples of alfalfa from field plats for chemical analysis. The plat was divided lengthwise into four strips of equal width for the systematic sampling. From each strip three square-yard areas were harvested, the areas being equidistant from each other and from the sides of the strips. The areas were staggered in respect to the distance from the end of the plat. Sets of samples were taken from Brookston clay loam, Isabella sandy loam, Mancelona gravelly sandy loam, and Fox sandy loam.

A summary of the analytical data obtained from the samples is presented in Table 13. Since only two samples were taken at random,

it is impossible to treat the data statistically. It appears, however, from a consideration of the averages of the percentages of the elements determined in the plants from each soil type, that there is little difference in favor of either method of field sampling. It may be concluded, therefore, that the data collected during the main portion of the investigation represent the average composition of the alfalfa on the plats studied as accurately as though a large number of samples had been taken according to a systematic pattern. The data from the systematic samples do show a considerable variation in composition of alfalfa from different portions of each plat.

TABLE 13.—*Comparisons of results from samples taken by the systematic and random methods of sampling, averaging 2 samples in case of the random method and 12 samples in the systematic method.*

Treatment	Sampling method	Moisture %	N %	CaO %	P_2O_5 %
		Mancelona Gravelly Sandy Loam			
None	Random	10.64	3.20	4.98	0.37
None	Systematic	11.63	3.13	4.75	0.36
600 lbs. 0-0-15	Random	11.76	2.89	2.55	0.40
600 lbs. 0-0-15	Systematic	10.30	2.87	2.54	0.37
		Brookston Clay Loam			
None	Random	10.29	2.98	3.35	0.49
None	Systematic	9.71	2.98	3.06	0.52
300 lbs. 0-20-0	Random	8.97	3.22	2.53	0.63
300 lbs. 0-20-0	Systematic	9.53	3.23	2.47	0.66
		Isabella Sandy Loam			
300 lbs. 0-16-0	Random	10.06	2.93	1.87	0.67
300 lbs. 0-16-0	Systematic	11.20	3.16	2.01	0.71
300 lbs. 4-16-4	Random	10.61	3.07	2.34	0.62
300 lbs. 4-16-4	Systematic	11.79	3.19	2.28	0.67
		Fox Sandy Loam			
Field 1, 250 lbs. 0-20-20	Random	11.72	3.14	1.88	0.57
Field 1, 250 lbs. 0-20-20	Systematic	11.00	3.30	2.00	0.65
Field 2, 250 lbs. 0-20-20	Random	10.21	3.51	1.91	0.71
Field 2, 250 lbs. 0-20-20	Systematic	10.56	3.59	2.09	0.75

GREENHOUSE EXPERIMENTS

The failure of alfalfa grown in the field on fertilized plats to show a consistent response in composition to the fertilizer treatment raised a question as to how definite a correlation between plant composition and fertilizer application alfalfa would show when grown under controlled conditions in the greenhouse.

The Montcalm sandy loam soil was selected for the greenhouse trials. This soil type is fairly widely distributed in the central part of the lower peninsula of Michigan. The soil is undulating to moderately rolling with good drainage, the supply of organic matter is moderate, and the soil is fairly productive and responds well to fertilizer treatment. An acidity requiring about 2 tons of limestone per acre is usually found.

The soil used in the experiments was screened to remove coarse material, thoroughly mixed, and 12-kilogram portions placed in 2-gallon glazed jars. Fertilizer applications as indicated in Table 14 were thoroughly mixed through the dry soil. During the experiment a moisture content of approximately 20% was maintained. All treatments were in duplicate, except 4, 5, 11, 12, 18, and 19, which were in sets of four. Plants were thinned to 10 per pot and good growth was obtained. All cuttings were made in the one-half bloom stage of growth for partial analysis. The first and second cuttings were combined into one sample for analysis as were the third and fourth cuttings.

TABLE 14.—*Effect of 2 tons of limestone plus increasing amounts of 20% superphosphate applied to Montcalm sandy loam soil on the phosphorus and nitrogen content of alfalfa grown in the greenhouse in 1932.*

Pot No.	Superphosphate, lbs.	1st and 2nd cutting			3rd and 4th cutting		
		Water %	N %	P_2O_5 %	Water %	N %	P_2O_5 %
	Series I. High Calcium Limestone Plus 100 lbs. Muriate of Potash						
1	None..........	11.25	4.25	0.98	7.59	3.55	1.06
2	200..........	12.81	4.23	1.00	7.51	3.31	1.04
3	400..........	14.75	4.24	1.05	7.21	3.34	1.03
4	800..........	9.39	4.26	0.94	7.23	3.51	0.99
5	1,200..........	9.82	4.19	0.98	7.59	3.51	1.03
6	2,400..........	10.18	4.22	0.97	8.11	3.48	1.15
7	4,800..........	10.52	4.22	1.13	8.56	3.51	1.35
	Average......	11.25	4.23	1.01	7.69	3.46	1.09
	Series II. High Calcium Limestone						
8	None..........	8.45	4.31	0.99	8.54	3.55	1.13
9	200..........	9.43	4.26	0.96	8.58	3.45	1.13
10	400..........	9.97	4.28	0.98	8.17	3.35	1.07
11	800..........	7.29	4.26	0.93	9.95	3.64	1.11
12	1,200..........	8.24	4.27	0.99	9.85	3.65	1.20
13	2,400..........	7.33	4.16	1.01	8.94	3.65	1.28
14	4,800..........	7.89	4.17	1.05	8.76	3.50	1.55
	Average......	8.37	4.24	0.99	8.97	3.54	1.21
	Series III. High Magnesium Limestone						
15	None..........	9.29	4.27	0.99	9.64	3.58	1.20
16	200..........	9.66	4.41	0.96	9.35	3.52	1.10
17	400..........	10.08	4.29	0.97	9.39	3.56	1.23
18	800..........	7.49	4.23	0.97	8.89	3.49	1.15
19	1,200..........	7.72	4.33	0.93	9.09	3.56	1.08
20	2,400..........	8.07	4.34	1.03	9.13	3.63	1.27
21	4,800..........	8.24	4.19	1.20	8.94	3.63	1.74
	Average......	8.58	4.29	1.01	9.20	3.57	1.25

Table 14 shows that the nitrogen contents of the second samples were decidedly and uniformly lower than those of the first. Soil treatment appeared to make no marked difference in nitrogen content of samples.

The phosphorus contents of the second samples were slightly but uniformly higher than those of the first samples. Heavy applications of superphosphate, 2,400 pounds and especially 4,800 pounds, increased the phosphorus content of the alfalfa in most cases. The results afford some basis for the suggestion that a considerable quantity of superphosphate must be added to this soil before an appreciable increase in the phosphorus content of the alfalfa can be expected. The large quantity of superphosphate required may explain why definite increases in phosphorus content of alfalfa, as a result of phosphorus fertilization, were not obtained in the field experiments reported early in this paper. On the average, application of limestone increased the phosphorus content of the plants in the third and fourth cuttings, but not in the first and second cuttings. The presence of magnesium in the limestone did not increase its effectiveness in this respect. These results are not in accord with those of Kellog (6), who found that magnesium oxide enhanced phosphate availability in soils. Truog (18) attributes this effect to a better calcium-magnesium soil balance in which event the plants are not forced to excess feeding on calcium in order to obtain phosphorus.

SUMMARY

1. This paper reports experimental data obtained from a partial chemical analysis of alfalfa grown on Isabella sandy loam, Montcalm sandy loam, Mancelona gravelly sandy loam, Fox sandy loam, Brookston loam, Brookston clay loam, Brookston silt loam, Gilford loam, and Miami silt loam.

2. The first cuttings of alfalfa grown on the several soil types exhibited a much lower ratio of leaves to stems than the second cuttings at the one-half bloom stage. Also, the weight of stems exceeded that of the leaves in the first cuttings, which was just the opposite of the condition for the second cutting.

3. In both the stems and leaves the nitrogen content tended to be higher in the second than in the first cuttings of alfalfa harvested in the one-half bloom stage.

4. Regardless of soil type and soil treatment the calcium content of alfalfa leaves was from two to three times greater than that of the stems.

5. In case of plants grown on Isabella sandy loam soil the calcium content of the stems tended to be higher in the second than in the first cuttings, but the opposite was true in the case of the leaves. In the other soil types, the data are not complete enough for such comparison.

6. Plants grown on the Isabella sandy loam show that all soil treatments containing limestone increased the nitrogen content of both the stems and leaves but tended to depress the phosphorus content.

7. In general, the plants grown on soils not requiring applications of limestone showed increases in the phosphorus content of both the stems and leaves with fertilizer treatments containing superphosphate alone or with potash.

8. Plants from the Gilford loam were markedly higher in calcium content than plants grown on the other soil types studied.

9. Alfalfa grown on Isabella sandy loam soil showed a decidedly higher phosphorus content in both the stems and leaves than that of plants from the other soil types.

10. Plants grown on Montcalm sandy loam soil in the greenhouse required very heavy applications of phosphate in order to increase their phosphorus content materially.

11. The phosphorus content of alfalfa grown on the soil types studied was not low compared to that of alfalfa from other states.

12. The data presented in this paper indicate no advantage of the systematic over the random method of taking samples of alfalfa for chemical analysis.

LITERATURE CITED

1. ALWAY, F. J., SHAW, W. M., and METHLEY, W. J. Phosphoric acid content of crops grown upon peat soils as an index of the fertilization received or required. Jour. Agr. Res., 33 : 701–740. 1926.
2. AMES, J. W., and BOLTZ, G. E. Nitrogen and mineral constituents of the alfalfa plant. Ohio Agr. Exp. Sta. Bul. 247. 1912.
3. ECKLES, C. H., BECKER, R. B., and PALMER, L. S. A mineral deficiency in the rations of cattle. Minn. Agr. Exp. Sta. Bul. 229. 1926.
4. FONDER, J. T. A critical study of the influence of soil type on the calcium and magnesium content and other physiological characters of the alfalfa plant. Soil Science, 27 : 205–232. 1929.
5. HOLTZ, H. F. Effect of calcium and phosphorus content of various soil series of western Washington upon the calcium and phosphorus composition of oats, red clover, and white clover. Wash. Agr. Exp. Sta. Bul. 243. 1930.
6. KELLOG, C. E. Magnesium—a possible key to the phosphorus problem in certain semi-arid soils. Jour. Amer. Soc. Agron., 23 : 494–495. 1931.
7. MATHER, T. H. The effect of fertilizers upon the forms of phosphorus and amounts of phosphorus, nitrogen, and silica in hays. Sci. Agr., 10 : 35–63. 1929.
8. MCCOOL, M. M., and WELDON, M. D. The effect of soil type and fertilization on the composition of expressed sap of plants. Jour. Amer. Soc. Agron., 20 : 778–792. 1928.
9. STUDIES BY THE CHEMISTRY DEPARTMENT. Fertilizers for forage plants. Mont. Agr. Exp. Sta. Rpt., 1928 : 37–39. 1928.
10. NEIDIG, R. E., MCDALE, G. R., and MAGNUSON, H. P. Effect of sulfur, calcium and phosphorus on the yield and composition of alfalfa on six types of Idaho soils. Soil Science, 16 : 127—136. 1923.
11. NYGARD, I. J. Phosphate deficiency in the soils of Montana. Mont. Agr. Exp. Sta. Bul. 240. 1931.
12. PITTMAN, D. W. Effect of manure and of phosphorus fertilizer on the yield and composition of alfalfa hay. Utah Agr. Exp. Sta. Bul. 247. 1934.
13. REIMER, F. C., and TARTAR, H. V. Sulfur as a fertilizer for alfalfa in southern Oregon. Ore. Agr. Exp. Sta. Bul. 163. 1919.
14. SATALA, J. Relation of maturity to the nutritive value of first, second and third cuttings of irrigated alfalfa. Jour. Agr. Res., 35 : 361–383. 1927.
15. SALMON, S. C., SWANSON, C. O., and MCCAMPBELL, W. C. Experiments relating to the time of cutting alfalfa. Kans. Agr. Exp. Sta. Tech. Bul. 15. 1925.
16. SEWELL, M. C., LATSHAW, W. L., and TAGUE, E. L. The effect of acid phosphate on soil reaction and growth of alfalfa. Proc. Intern. Congr. Soil Sci., Comm. 2 : 439–455. 1927.
17. ————, ————. The effect of lime, superphosphate, and potash on reaction of soil and growth and composition of alfalfa. Jour. Amer. Soc. Agron., 23 : 799–816. 1931.
18. TRUOG, E. Available calcium and magnesium in relation to phosphate utilization. Jour. Amer. Soc. Agron., 23 : 1055. 1931.

ONE ASPECT OF THE INTERRELATION OF SOIL BACTERIA AND PLANT GROWTH[1]

NORMAN ASHWELL CLARK[2]

THE influence of micro-organisms on the soil has been known since 1875, when bacteria were shown to attack soil organic material and form nitrates. In recent years it has been suggested that micro-organisms may affect the green plant by producing unknown substances in soil organic matter which are either essential for growth or which influence markedly the composition of the plant.

Very small amounts of organic matter have a noticeable effect on the growth of plants in water cultures. Bottomley (1)[3] and Mockeridge (8) at the University of London, in their experiments with the plant Lemna, could not obtain growth and reproduction in inorganic salt solutions without adding extracts from soil or manure. They came to the conclusion that organic matter of a special kind, present in soils, peats, and farmyard manure, was *essential* for good growth of green plants, and that these unknown compounds were the result of bacterial action. They believed that these compounds were similar to vitamins in animal life and that they were just as essential for plant life.

That organic matter was not necessary for the growth and reproduction of Lemna was shown by Clark and Roller (4), and confirmed by others, but the possibility remained that the composition of the plant was affected. The known value of farmyard manure in the production of crops and the experiments on plant growth of Schreiner and Skinner (10) and others in the Bureau of Soils, of Wolfe (14), and of Clark and Roller (5) with Lemna under sterile conditions indicated that, while many organic compounds would not stimulate plant growth, some special organic substances, particularly in the presence of micro-organisms, could affect the plant. This view is also held by a number of workers in southern India, among them McCarrison (7) and Viswa Nath (13).

Viswa Nath (12) believes micro-organisms in the soil act on organic matter and liberate some active constituent which is absorbed by the plant. This is either passed to the seed or causes some special metabolism in the plant, producing substances which are not formed without the active constituent. This belief is based upon a large number of experiments on grains in India, particularly at the Agricultural Research Institute at Coimbatore. One of the interesting observations made is that seeds from plats under various fertilizer treatments give large variations in the following crops under the same treatments. Millet obtained from plats receiving farmyard manure produced better crops than millet from plats receiving commercial fertilizers

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[3]Figures in parenthesis refer to "Literature Cited," p. 103.

when both lots of seed were sown under the same conditions the following season.

McCarrison (7) carried out animal nutrition experiments with the grain obtained from differently fertilized plats, and as before, the grain from the farmyard manure plat proved of greater value than that from plats with mineral fertilizers, but neither size nor composition of the grain showed appreciable differences. McCarrison attributed the difference to the vitamin content, and in experiments on pigeons and rats, both with millet and wheat, found that the vitamin B content was distinctly higher in the grain from plats treated with cattle manure, and also found indications that pointed to the same fact for the vitamin A content.

From these results Viswa Nath (13) argued that, as the grain from the cattle-manured plats was richer in plant growth stimulant and also in vitamins, the plant stimulant and the vitamin might be either the same, or else interrelated so that the stimulant would enable the plant to form the vitamins. He found that the more decomposed the manure, the greater the amount of plant stimulant in the seed. Yeast, known to produce vitamins, also stimulated plant growth. The suggestion was that micro-organisms are concerned in the process of stimulant production, the final conclusion being that the chain reaches from the bacteria at the start, through the organic matter, the plant-stimulating substances, the vitamins produced in the plant, to the utilization of these in animal life. The importance to south India, where millet is the main staple in the diet of thousands, is obvious. The theory is similar to that of Bottomley and Mockeridge of 15 years ago, without the emphasis on the presence of organic matter as essential to the life of the green plant.

There are two investigations which bear upon this theory. In 1927, Hunt (6) reported on the vitamin B content of wheat which had been grown on plats under varying fertilizer treatment for some 35 years. He found little or no influence due to the varying treatments, although from year to year the B content varied widely, indicating a climatic effect. In 1932, Virtanen and van Hausen (11) of Finnland grew peas under sterile and non-sterile conditions. They determined carotin in the plants, but found no marked difference in quantity. Vitamin C was also checked by a chemical method with similar results. It may be noted that the peas here were only one generation away from the soil and presumably might have contained the stimulant in sufficient quantities to produce the vitamins.

At Iowa State College we had grown Lemna for several years through hundreds of generations in the absence of micro-organisms and in inorganic salt solution, as well as non-sterile plants on a soil-water mixture. The Lemna can produce flowers, but usually propagates asexually by putting out a small frond or leaf which grows to the size of the parent and then separates. Here was an opportunity to test the presence or absence of vitamins in plants which were completely out of the influence of micro-organisms.

The writer interested Dr. B. H. Thomas in the problem. Dr. Thomas, who was working with vitamin A on a large colony of rats agreed to test the Lemma with the rats. Seventeen rats of about the

same size and development were selected and were placed on a diet devoid of vitamin A but containing everything else necessary. At the time the experiments started these rats had ceased to increase in weight for several days and had developed marked xerophthalmia.

The rats were divided into four groups. The controls were fed the basal A-free ration. Of these, three died before the end of the experiment and the fourth a few days later. The second and third groups were used for a comparison of the vitamin A in plants grown in a non-sterile mixture of soil-water and in those reproducing free of micro-organisms in a purified salt solution. These plants were collected each week, air dried in the dark, and after being finely ground, were included in the basal ration to the extent of 0.5% dry weight. The fourth group of rats was fed daily, by hand, 0.25 gram each of the fresh green plants from the soil, this amount providing approximately the same weight of dry matter from the Lemna as that consumed by those taking the dry plants.

The results were never in doubt. All three groups receiving the Lemna showed the results of the vitamin A almost at once. The xerophthalmia cleared up and the rats started to gain weight. The weight curves for those on the dry sterile plants parallelled very closely the curves for those on the non-sterile plants. The average gain for the 24 days was 29 grams for each rat. The rats on the fresh plants put on weight somewhat faster, suggesting that part of the vitamin had been destroyed by the drying process. This loss on drying has been observed before with other green plants.

The uniform rate of growth made by the two groups which received sterile and non-sterile plants is an indication that not only is the vitamin formed in plants which have been removed from the influences of micro-organisms for hundreds of generations, but also that there is little difference in the quantity produced. A secondary item of interest is that while the non-sterile Lemna were grown principally in sunshine, the sterile plants were produced under electric light (3).

In these experiments the absence of the micro-organisms and the variation in light have had little influence on the formation of vitamin A in the Lemna. But vitamin A is probably not produced to any extent by bacteria, and for other vitamins there might be quite different results. It was for vitamin B that McCarrison's results were most evident, and that particular vitamin is produced by bacteria. The writer cannot yet report successful experiments with vitamin B.

An attempt was made to check vitamin B, not distinguishing between B and G, by feeding the fruit fly, *Drosophila melanogaster*, as it has been reported that vitamin B is essential for these flies. The larvae feed on yeast, which of course contains vitamin B, but it was not possible to get them to grow when freed from micro-organisms on a synthetic medium, with the vitamin B of the extracted yeast added to the medium. We thought to substitute the Lemna extract for the yeast extract. This would have needed a far smaller quantity of the Lemna plants than rat feeding, and the production of the sterile plants is time consuming.

At the present time, therefore, we have an open mind on the question. We believe that green plants will grow, remain healthy, and

reproduce without any organic matter or bacteria. We believe that certain types of organic substances, expecially in the presence of bacteria, may markedly effect the plant constitution, but whether this is due to the formation of an auximone, or its connection with vitamins, we do not know.

Olsen (9), at the Carlsberg Laboratories in Denmark, believes that the whole effect is in the iron supply. The iron in the organic combination is more available to plants, whereas in most combinations when the pH of a solution is higher than 5, iron tends to precipitate as ferric hydroxide and becomes unavailable to the plant. Burke, *et al.* (2) has pointed out that the Fe humate combination, whether a true chemical combination or colloidal, holds the iron in solution at higher pH values, thus keeping it available for plants. Burke also showed that the growth of Azotobacter responded quantitatively to the Fe content when organic matter was added. It does not look, however, as if the iron would be responsible for the change in feeding value of grains as given by McCarrison; and Viswa Nath certainly does not agree with this explanation.

The problem of the effect of organic matter on the plant and the part played by bacteria is still unsettled.

LITERATURE CITED

1. Bottomley, W. B. The growth of Lemna plants in mineral solutions and in their natural medium. Ann. Bot., 34 : 345–352. 1930.
2. Burke, D., *et al.* The relation of iron, humic acid, and organic matter in the nutrition and stimulation of plant growth. Science, 74 : 522–524. 1931.
3. Clark, N. A. Technique for the growth of Lemna under sterile conditions. Iowa State Jour. Sci., 7 : 13–16. 1932.
4. ———— and Roller, E. M. Auximones and the growth of the green plant. Soil Science, 17 : 193–197. 1924.
5. ————, ————. The stimulation of Lemna major by organic matter under sterile and non-sterile conditions. Soil Science, 31 : 299–309. 1931.
6. Hunt, C. H. The influence of fertilizers on the vitamin B content of wheat. Ohio Agr. Exp. Sta. Bul. 415. 1927.
7. McCarrison, R. The effect of manurial conditions on the nutritive and vitamin values of millet and wheat. Indian Jour. Med. Res, 14 : 351–378. 1926.
8. Mockeridge, F. A. The occurrence and nature of the plant growth-promoting substances in various organic composts. Biochem. Jour., 14 : 422–450. 1920.
9. Olsen, C. On the influence of humus substances on the growth of green plants in water culture. Compt. rend. Lab. Carlsberg, 18 : 1–16. 1920.
10. Schreiner, O., and Skinner, J. J. Nitrogenous soil constituents and their bearing on soil fertility. U. S. D. A. Bur. Soils Bul. 87. 1912.
11. Virtanen, A. I., and van Hausen, S. Die Vitaminbildung in Pflanzen. Naturwissenschaften, 20 : 905. 1932.
12. Viswa Nath, B., and Suryanarayana, M. The effect of manuring a crop on the vegetative and reproductive capacity of the seed. Mem. Dept. Agr. India, 9 : 85–124. 1927.
13. ————. Some aspects of plant nutrition. Agr. Res. Inst. Coimbatore. 1932.
14. Wolfe, H. S. The auximone question. Bot. Gaz., 81 : 228–231. 1926.

THE RHYTHMICAL NATURE OF MICROBIOLOGICAL ACTIVITY IN SOIL AS INDICATED BY THE EVOLUTION OF CARBON DIOXIDE[1]

F. B. SMITH, P. E. BROWN, AND H. C. MILLAR[2]

THE factors influencing the production of carbon dioxide in soils have been the subject of many investigations. The evolution of carbon dioxide from soils has long been regarded as a measure of microbiological action, although it is now recognized that this may be a rather liberal interpretation of the facts. However, numerous experiments have shown a fair degree of correlation between the amounts of carbon dioxide produced in soils and the numbers of micro-organisms present. Experiments have also shown a relationship between the evolution of carbon dioxide from soils and the activity of certain physiological groups of soil micro-organisms.

It is common knowledge that microbiological activity in soils may be increased at first and then decreased when field soils are brought into the laboratory. This stimulation is evidenced by an increase in numbers of organisms and also by an increase in the amount of carbon dioxide produced.

Johansson (3)[3] observed a regular periodic fluctuation in the production of carbon dioxide in forest soils when the soils were incubated in the laboratory under control conditions. He also found that the amount of carbon dioxide produced during the day was often greater than the amount produced during the night.

The purpose of this investigation was to determine the rate of evolution of carbon dioxide from soils variously treated and to study the relationship of carbon dioxide production to microbiological activity in soils. The data reported in this paper are the results of preliminary work done on the first part of the problem.

METHODS OF PROCEDURE

The amount of carbon dioxide evolved from the soil was determined at 12-hour intervals for periods of 5 to 15 days. Duplicate samples of the moist soil which had been passed through the 2-mm sieve and thoroughly mixed were weighed out and placed in 400-cc beakers. Samples of the moist soil equivalent to 400 grams of the dry soil were used and the moisture content adjusted to 25% by the addition of distilled water. The beakers containing the soil were then placed in respiration chambers and incubated at 27° to 28°C.

The respiration chambers used in these experiments were made from 1-gallon tin buckets and are similar in principle to the apparatus described by Lundegardh (4), Fehér (2), and Johansson (3). A wire loop was soldered inside the bucket to support the beaker containing the sample of soil. A hole was cut in the

[1]Contribution from Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Published as Journal Paper No. J202 of the Iowa Agricultural Experiment Station. Project No. 231. Also presented at the annual meeting of the Society in Washington, D. C., November 23, 1934. Received for publication November 23, 1934.

[2]Associate Professor, Professor, and Fellow, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 108.

opposite side of the bucket and a ¼-inch collar soldered on the outside. A No. 7, two-hole rubber stopper fitted with a tube for introducing the barium hydroxide and with a guard tube of soda-lime was placed in this opening. Another opening was made in the bottom of the bucket and fitted with a tube closed by a pinch cock. The barium hydroxide was drained from the bucket for titration without disturbing the sample. Three pieces of No. 9 galvanized iron wire 8 inches long soldered on served as legs to support the buckets (Fig. 1).

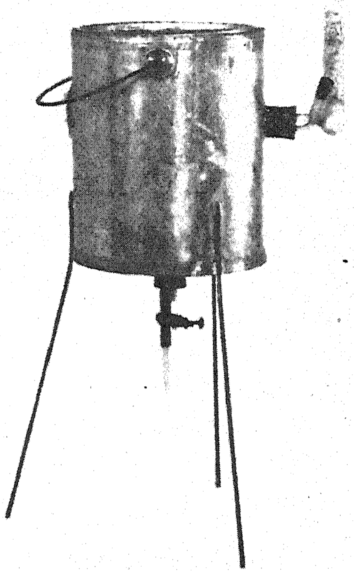

FIG. 1.—Respiration chamber.

The inside of the buckets was covered with paraffin. The samples were placed in the buckets and the lids sealed air-tight with paraffin. Fifty cc of 0.1 N barium hydroxide were added through the tube provided for this purpose. The amount of carbon dioxide was determined by titrating the barium carbonate and excess barium hydroxide against 0.1 N hydrochloric acid, using phenolphthalein as the indicator.

Two series of experiments were conducted from which samples of soil were taken for the laboratory tests. In the one series, field soils which had been treated previously were sampled and the evolution of carbon dioxide determined in the laboratory at 12-hour intervals for 5 to 15 days. In the other series, soils treated in the greenhouse in 4-gallon pots were sampled at regular intervals and the evolution of carbon dioxide determined in the laboratory at 12-hour intervals for 10 to 11 days.

RESULTS

SERIES I

Seven plats of Carrington loam 14 by 56 feet with 7-foot borders were treated May 20. The soils were kept fallow and samples for carbon dioxide production determinations taken June 20 and August 20. The average rates of carbon dioxide production for all treatments in the two experiments are shown in Fig. 2.

The data showed a small but significant difference in the rate of carbon dioxide evolution in the soils from the different plats one month after treatment, but these differences had disappeared three months after treatment. However, the rate of production of carbon dioxide at the 12-hour periods fluctuated similarly in all soils and the average rates of production only are shown for the two experiments.

An analysis of variance of the data showed a highly significant difference in the average rate of production of carbon dioxide between the 12-hour periods. In both experiments the average rate of pro-

duction of carbon dioxide decreased rapidly during the first 36 hours, then the rate of production fluctuated more or less regularly at 12-hour intervals between high and low values. The difference between the maximum and minimum values gradually became smaller as the experiment continued until the 12th day in the second experiment when a high maximum rate of production was attained. The rate of production of carbon dioxide after the first 36 hours was usually

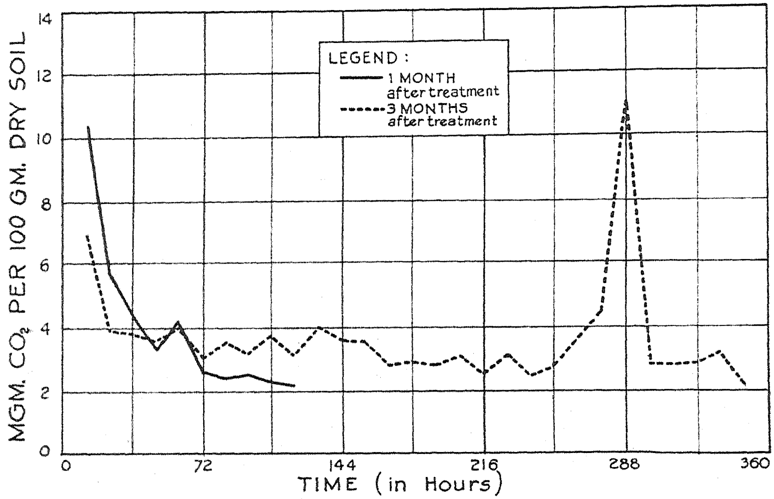

FIG. 2.—Average rate of carbon dioxide production in field soils sampled one month and three months after treatment.

higher during the day than during the night. However, the highest rate of production in the second experiment was obtained during the night period.

SERIES II

The soil used in this series of experiments was a Carrington loam having a pH of 6.33. The soil was taken from the College agronomy farm in a permanent pasture. In securing the soil the grass sod was removed and the soil below was taken to a depth of 6 inches. It was brought into the greenhouse, passed through a quarter-inch screen, and thoroughly mixed. Thirty-nine pounds of soil were placed in each of 32 4-gallon pots.

Two series of 16 pots each were set up and 4 pots of soil in each series were treated according to the following outline, the materials being thoroughly mixed with the soil:

A, Check
B, 0.2% oat straw
C, 0.2% oat straw and 0.2% rock phosphate
D, 0.2% oat straw, 0.2% rock phosphate, and 0.1% limestone

The oat straw used was ground to pass the 0.5-mm sieve and contained 0.61% nitrogen. The rock phosphate was approximately 100-mesh and contained 31.82% P_2O_5. The limestone was about 40-mesh and contained 80% calcium carbonate.

The soils in four pots of each of these treatments received no further treatment (Series 1) and served as checks. Carbon dioxide-saturated water, referred to as carbonic acid and having a pH of 4.2, was added to the soils of four pots of each treatment (Series 2). The moisture content of the soil was adjusted to 20% and maintained at that amount throughout the experiment by the addition of distilled water except in the case of Series 2 where carbonic acid was used. The soils

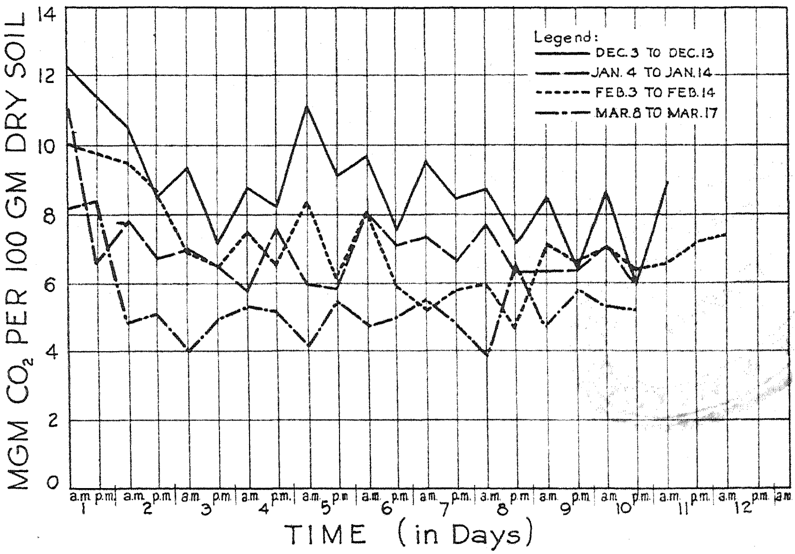

FIG. 3.—Average rate of carbon dioxide production in greenhouse soils.

of one pot of each treatment were kept fallow and samples taken at intervals for the determination of the production of carbon dioxide in the laboratory. The two series of experiments and the four treatments in each series are illustrated in the following outline:

No.	Series 1 (check)	Series 2 (carbonic acid treated)
1	Untreated	Untreated
2	Straw	Straw
3	Straw + phosphorus	Straw + phosphorus
4	Straw + phosphorus + lime	Straw + phosphorus + lime

The soils were treated in the greenhouse November 1 and samples taken for determining the rate of carbon dioxide evolution December 3, January 4, February 3, and March 8. The average rates of carbon dioxide production at the different samplings are shown in Fig. 3.

The data showed a highly significant difference between the rate of production of carbon dioxide in the differently treated soils, but the fluctuations in the rate of production at the 12-hour periods were similar and only the average rate of production in each experiment is given.

DISCUSSION OF RESULTS

The data obtained in the foregoing experiments show that the rate of carbon dioxide production in soils decreased rapidly during the first one to three days of incubation in the laboratory. The initial period of decreasing rate of production was usually followed by a period of regular fluctuations between high and low rates of production and then the cycle was repeated. A statistical analysis of the data showed that these fluctuations were not merely chance variations, but that there was a highly significant tendency toward a rhythmical periodicity in production of carbon dioxide in the soils.

Bal (1) has investigated the decreasing rate of production of carbon dioxide in soils incubated in the laboratory and found that it was not caused by a lack of available carbon nor by soluble toxic substances produced by the organisms themselves.

Johansson (3) stated that the periodicity in the rate of carbon dioxide production could be explained if one assumes a variation in the rate of metabolism of the soil micro-organisms or fluctuations in the growth velocity. The latter assumption, it was pointed out, is supported by evidence that the rate of cell division of some of the higher plants is greater during the day than during the night.

The data obtained in these experiments show that there was no correlation between the amount of carbon dioxide produced during the day or at night and the periods of high rate of production. That there were rather definite cycles between the periods of high and low rates of production, there can be no doubt but the 12-hour intervals were too long to define these periods accurately.

There is no experimental evidence for the assumption that there are periodic variations in the rate of respiration of the organisms. However, the amount of carbon dioxide produced during the various phases of growth in a bacterial culture might vary. That is, during the logarithmic growth phase, more carbon might be required for the metabolism of cells and a smaller proportion used for energy but with an increasing number of cells respiring. During the logarithmic death phase a larger proportion of carbon might be used for energy purposes than for cell metabolism, but there are also a decreasing number of cells to respire during this phase. Even if this were the explanation of the phenomena, it would be difficult to conceive of a mixed culture of soil micro-organisms having generation time and metabolic processes sufficiently similar to produce regular periodic fluctuations in the rate of carbon dioxide production. The problem is being studied further with the hope of defining more clearly the relationship between carbon dioxide production and microbiological action in soils.

LITERATURE CITED

1. Bal, D. V. Studies on carbon dioxide production in soil and solution. Ann. Appl. Biol., 13 : 231–243. 1926.
2. Fehér, D. Ueber die Verwendung des Glockenapparatus von Lundegardh für die Messung der CO_2 Produktion des Waldbodens. Biochem. Zeitschr., 193 : 350–355. 1928.
3. Johansson, N. Rhythmische Schwankungen in der Aktivität der Mikroorganismen des Bodens. Svensk Botanisk Tidskrift, 23 : 241–260. 1929.
4. Lundegardh, H. Carbon dioxide evolution and crop growth. Soil Science 23 : 417–454. 1927.

THE DECOMPOSITION OF LIGNIN AND OTHER ORGANIC CONSTITUENTS BY CERTAIN SOIL FUNGI[1]

F. B. SMITH AND P. E. BROWN[2]

THE significance of organic matter in the soil is apparent from the definition of soil, for without it there is no soil. The organic matter of the soil is derived from plant and animal remains, and it exists in all stages of decomposition. De'Sigmond (1)[3] has grouped these stages into four classes, namely, (a) the raw undecomposed dead organic matter, (b) the solid decomposed material, (c) the material soluble or dispersed in the soil solution, and (d) the more or less volatile end products, such as carbon dioxide, ammonia, and hydrogen. It is apparent from this classification of organic matter that in time it will all disappear completely from the soil unless additions are made more or less regularly.

Numerous investigations have been conducted to study the influence of age of the plant, the chemical composition of the plant, and the kind of organic matter upon the rate of decomposition of plant materials. The factors influencing the growth of micro-organisms, such as reaction, temperature, moisture, and oxygen requirements, have probably received more attention than any other phases of the subject. Recently, the results of considerable study on fermentations have been reported, but much of this work has involved merely a determination of the products formed by specific organisms upon a given substrate. It would seem desirable to study the rate of decomposition of the fertilizing materials which supply organic matter on the farm or of some of the principal constituents of this organic matter. The purpose of this work was to determine the rate of decomposition of several forms of organic matter when acted upon by certain common soil fungi. This paper is a progress report on the project.

METHODS OF PROCEDURE

Experiments were conducted to determine the rate of decomposition of lignin, xylan, cellulose, and oat straw. Pure cultures of *Trichoderma lignorum*, *Aspergillus terreus*, *A. niger*, *Penicillium vinaceum*, *Stereum purpureum*, and a soil infusion were used for the inoculation. In these experiments soil, sand, or a mineral salt solution were employed as the medium. The rate of decomposition was measured by the evolution of carbon dioxide.

The xylan and lignin were prepared by the method of Peterson and Hixon (2). The analysis of the xylan showed the following:

Moisture (loss at 100°C)	14.79%
Ash	17.33%
Carbon	28.46%
Pentosan (by furfural)	64.15%

[1]Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Published as Journal Paper No. J-152 of the Iowa Agricultural Experiment Station. Project No. 225. Also presented at the annual meeting of the Society held in Washington, D. C., November 23, 1934. Received for publication November 23, 1934.

[2]Associate Professor and Professor, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 119.

The analysis of the lignin showed:

Moisture (loss at 100°C)	7.72%
Ash	1.09%
Carbon	44.53%
Lignin (72% H_2SO_4)	88.66%

The cellulose used was prepared by extracting the residue after the NaOH extraction twice with dilute HNO_3. The residue was then washed free of HNO_3 and treated with $NaHSO_3$. The material was suspended in water and SO_2 bubbled through it, after which it was washed and dried. The analysis of this material showed:

Moisture (loss at 100°C)	4.78%
Ash	7.42%
Carbon	26.34%
Cellulose	78.97%

RESULTS

DECOMPOSITION OF XYLAN, LIGNIN, AND CELLULOSE IN CARRINGTON LOAM BY *Aspergillus terreus*, *Trichoderma lignorum*, AND *Penicillium vinaceum*

One hundred gram equivalents of dry Carrington loam which had been passed through the 2-mm sieve were weighed out on a paper and the material used as a source of carbon mixed thoroughly with the soil, then placed in a calibrated, 1-liter Erlenmeyer flask. The lignin, xylan, and cellulose were added to the soils in amounts equivalent to 300 mgm of carbon. The moisture content of the soil was adjusted to 25% and the flasks plugged with cotton, and sterilized at 15 pounds pressure for 1 hour on each of three consecutive days. Plates poured from soils sterilized in this manner never showed growth and the soils were considered to be sterile.

The organisms used to inoculate the soils were grown on agar slants for one week, after which 10 cc of sterile tap water were added, the tube shaken, and a 1-cc suspension taken for inoculation. After inoculation the flasks were fitted with a sterile 2-hole rubber stopper which carried an inlet tube, an outlet tube, and a mercury-seal stirrer. The flasks were then placed in the water bath at a temperature of 30°C and carbon dioxide determined volumetrically at intervals. The results obtained are shown in Figs. 1 and 2.

Aspergillus terreus.—Xylan was decomposed more rapidly at first than cellulose by *A. terreus*, but after 140 hours the cellulose was decomposing more rapidly than the xylan (Fig. 1). Approximately 500 mgm of carbon dioxide were evolved from the soil treated with cellulose and 320 mgm from the soil treated with xylan. The carbon dioxide equivalent of carbon added in each case was 1,100 mgm. The soil treated with lignin evolved a slightly greater amount of carbon dioxide than the untreated soil.

Trichoderma lignorum.—Cellulose was decomposed more rapidly than xylan at first by this organism, but the trend was reversed after about 200 hours (Fig. 2). Slightly more carbon dioxide was produced in the untreated soil than in the soil treated with lignin.

Penicillium vinaceum.—Growth was poor at first in all soils inoculated with this organism (Fig. 2). After 500 hours the soil treated with xylan had evolved a total of 233 mgm of carbon dioxide. Carbon dioxide production by the organism in the soil treated with lignin was slightly less than that of the check soil and only slightly greater in the soil treated with cellulose.

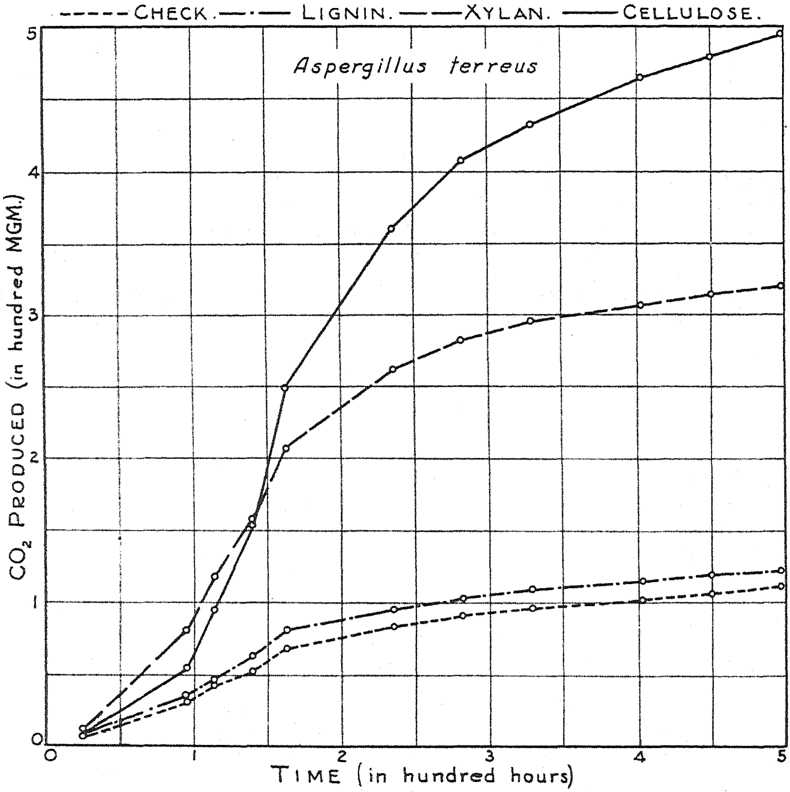

FIG. 1.—Decomposition of lignin, cellulose, and xylan by *A. terreus* in the soil.

DECOMPOSITION OF XYLAN, CELLULOSE, AND LIGNIN IN A SOLUTION CULTURE MEDIUM BY *Trichoderma lignorum*, *Aspergillus terreus*, AND *Penicillium vinaceum*

In this series of experiments the materials were added to 100 cc of a culture solution consisting of the following:

Peptone	0.5%
KH_2PO_4	0.1%
$MgSO_4$	0.05%
Distilled water	1 liter

One hundred cc of this solution were placed in 500-cc extraction flasks and sterilized 15 minutes at 15 pounds pressure. After sterilization the flasks were inoculated and placed in the culture room at a

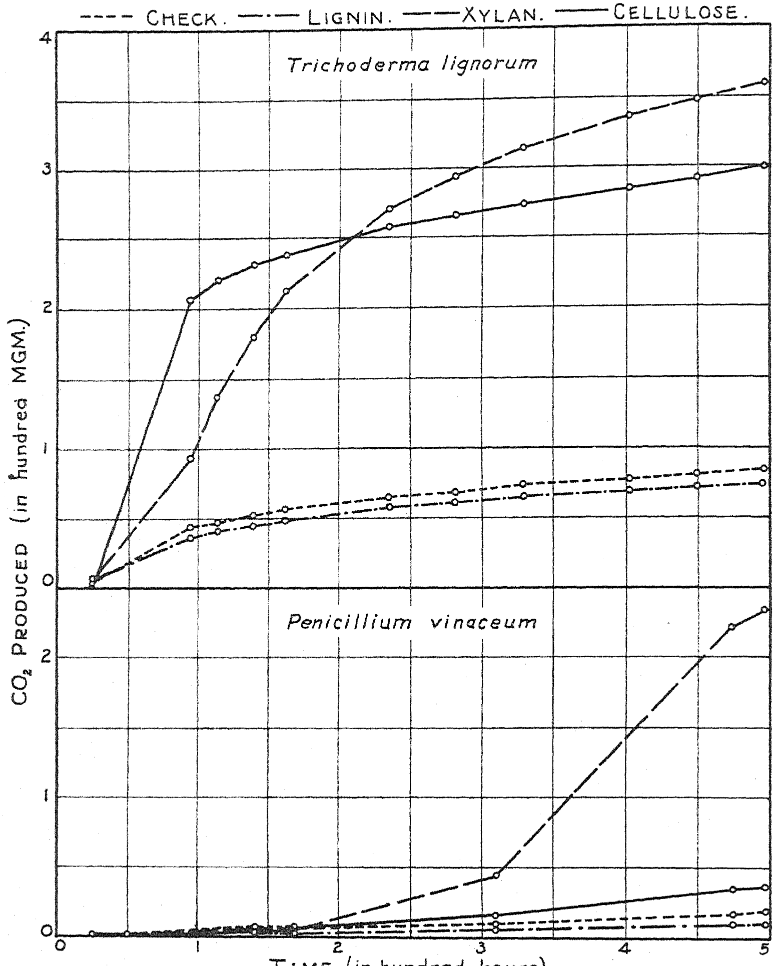

FIG. 2.—Decomposition of lignin, cellulose, and xylan by *T. lignorum* and *P. vinaceum* in the soil.

temperature of 28°C. Carbon dioxide-free air was drawn through the cultures and the carbon dioxide evolved absorbed in approximately 0.5 N KOH. The carbon dioxide was determined by titrating the excess KOH with standard HCl after the addition of $BaCl_2$. The results obtained are presented in Figs. 3 and 4.

Aspergillus terreus.—The initial rate of carbon dioxide evolution was largest where lignin or cellulose was used, but after 96 hours

carbon dioxide evolution was less rapid with these materials than in the peptone medium alone (Fig. 3). During the interval from 48 to 96 hours, carbon dioxide was being evolved more rapidly from the xylan than from the check, but after 400 hours only 69 mgm more carbon as carbon dioxide had been evolved.

In an inorganic salts solution with KNO_3 as a source of nitrogen instead of peptone, *A. terreus* decomposed xylan rapidly during the

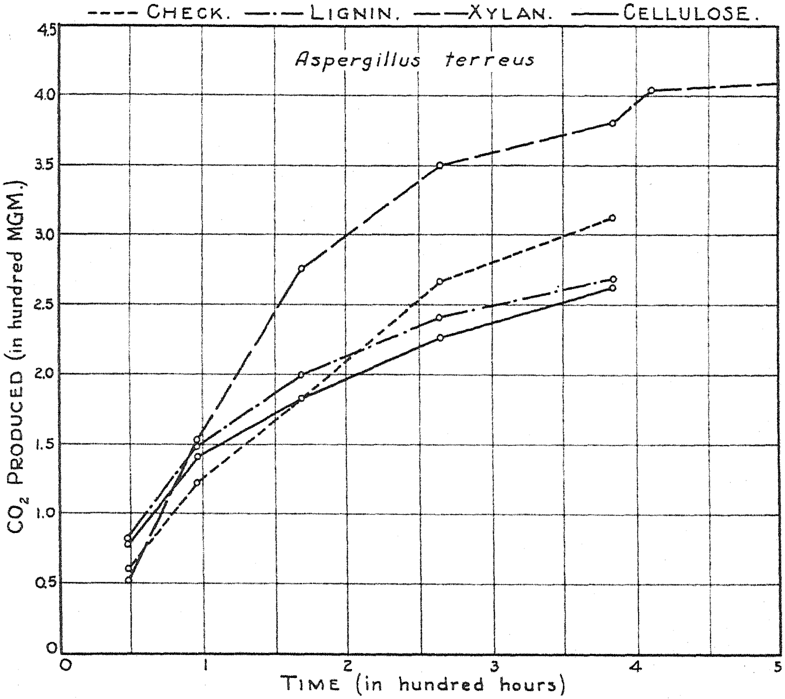

FIG. 3.—Decomposition of lignin, cellulose, and xylan by *A. terreus* in a peptone medium.

first 300 hours, after which the rates of decomposition of xylan and cellulose were approximately the same (Fig. 5). Of the 100 mgm of carbon added as xylan, 55 mgm were evolved as carbon dioxide after 450 hours. Some decomposition of cellulose and lignin occurred during this time, 21 and 20 mgm, respectively, of the 100 mgm of carbon added being evolved as carbon dioxide.

Trichoderma lignorum.—There was a slight stimulation in the initial rate of carbon dioxide evolution with all the materials inoculated with *T. lignorum* over that in the check (Fig. 4). With lignin and cellulose there was slightly less carbon dioxide finally than in the check, whereas when xylan was used there was slightly more carbon dioxide than in the check.

Penicillium vinaceum.—Xylan, lignin, and cellulose stimulated carbon dioxide production by *P. vinaceum* during the period from 48

to 168 hours, but all the treated cultures yielded less carbon dioxide than the check after about 400 hours of incubation (Fig. 4).

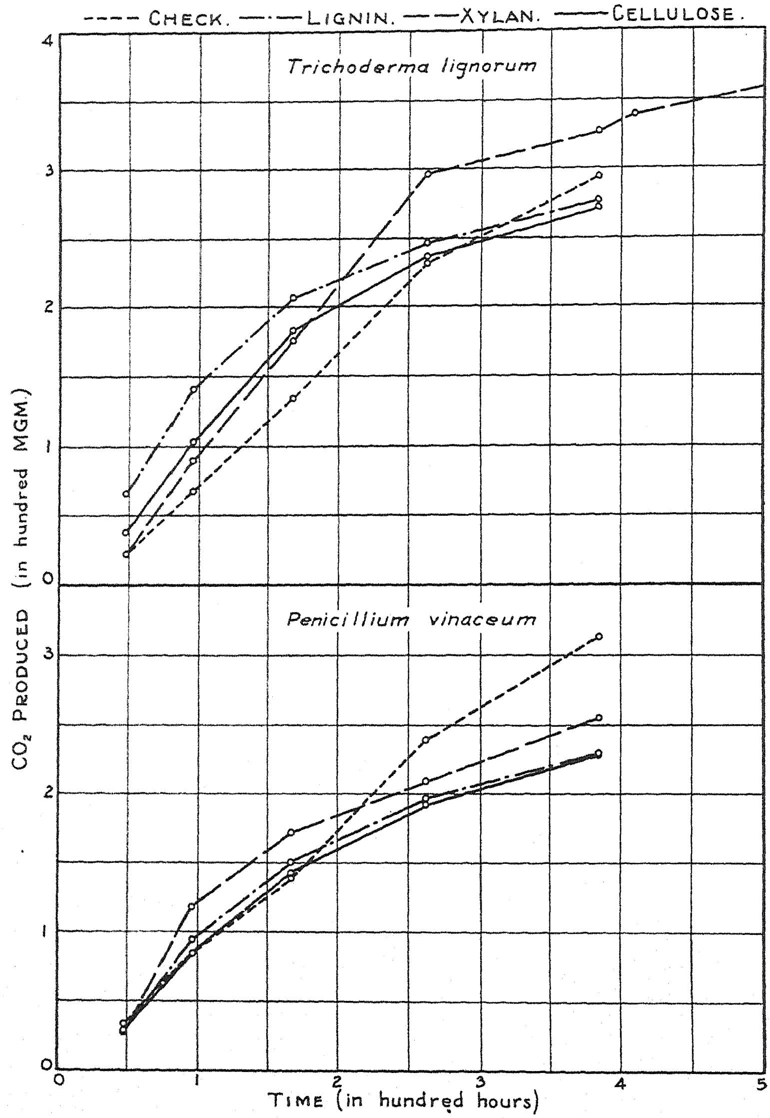

FIG. 4.—Decomposition of lignin, cellulose, and xylan by *T. lignorum* and *P. vinaceum* in a peptone medium.

DECOMPOSITION OF XYLAN, LIGNIN, CELLULOSE, AND OAT STRAW IN SAND BY *Aspergillus niger* AND A MIXED CULTURE OF SOIL MICRO-ORGANISMS

Three hundred grams of pure quartz sand were thoroughly mixed with 0.3 gram of carbon as xylan, cellulose, or lignin in a Fernback flask. Quadruplicate flasks were treated with each of the materials and four flasks were left untreated. The moisture content was adjusted at 5% and the flasks sterilized at 15 pounds pressure for 30 minutes on each of three successive days. After sterilization they were inoculated with a 10-cc suspension of the organisms and the moisture content adjusted to 25% by the addition of a sterile nutrient solution which contained 0.24% ammonium sulfate, 0.02% monopotassium phosphate, and 0.02% magnesium sulfate. The treatments were as follows:

Flask No.	Organism	Carbon source
1	*A. niger*	None
2	*A. niger*	None
3	*A. niger*	Xylan
4	*A. niger*	Xylan
5	*A. niger*	Cellulose
6	*A. niger*	Cellulose
7	*A. niger*	Lignin
8	*A. niger*	Lignin
9	*A. niger*	Straw
10	*A. niger*	Straw
11	Soil infusion	None
12	Soil infusion	None
13	Soil infusion	Xylan
14	Soil infusion	Xylan
15	Soil infusion	Cellulose
16	Soil infusion	Cellulose
17	Soil infusion	Lignin
18	Soil infusion	Lignin
19	Soil infusion	Straw
20	Soil infusion	Straw

The flasks were placed in the culture room and incubated at 28°C for 13 days and the carbon dioxide evolved determined by aspiration with carbon dioxide-free air and absorption in KOH. The results are presented in Table 1.

The data in the table show that the decomposition of straw follows essentially the decomposition of cellulose and xylan by *A. niger* and the soil infusion. In the case of both cultures the initial decomposition of straw follows that of the decomposition of cellulose, then it follows more nearly the course of the decomposition of xylan. A slight initial decomposition of lignin by *A. niger* and some depressing effect at the end of the experiment were indicated.

TABLE 1.—*Milligrams of carbon dioxide produced by A. niger and a mixed culture of soil micro-organisms in sand from various organic constituents.*

Time in hours	Check		Lignin		Xylan		Cellulose		Straw	
	A*	B*	A	B	A	B	A	B	A	B
30	2.5	6.1	3.6	5.3	4.0	1.9	11.7	23.2	10.0	24.8
59	8.7	13.1	8.8	12.1	9.5	27.0	21.8	50.3	26.1	57.7
96	13.5	16.8	14.7	18.8	27.6	75.6	29.6	72.1	41.3	104.0
144	22.3	25.7	19.9	23.0	104.2	131.8	37.5	98.3	62.6	142.5
192	32.6	30.4	26.7	29.1	193.8	186.4	47.8	125.3	102.4	198.8
246	40.4	35.0	30.1	38.3	261.0	241.9	62.8	159.5	141.9	222.4
312	54.3	44.1	43.7	46.4	337.9	301.9	78.1	190.1	173.7	253.9

*A = *A. niger*; B = Soil infusion.

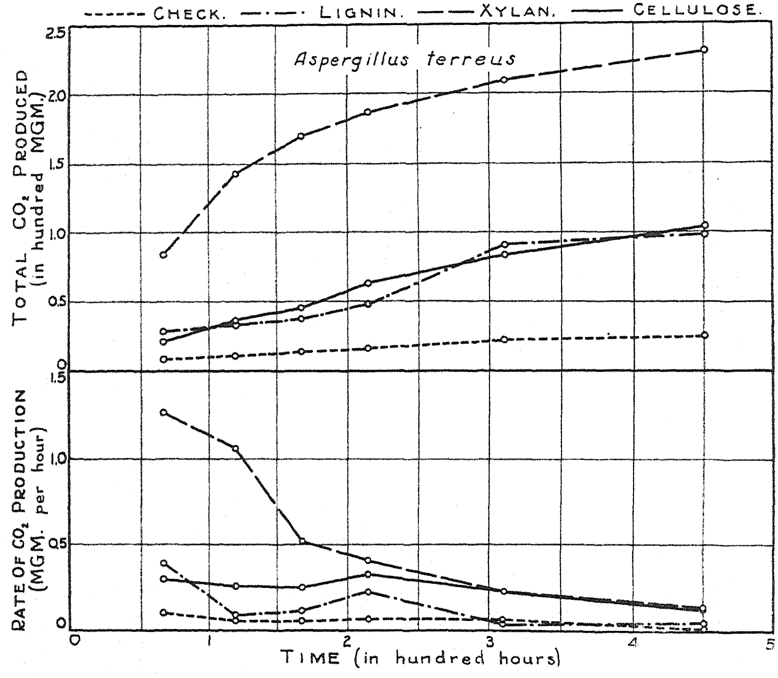

FIG. 5.—Decomposition of lignin, cellulose, and xylan by *A. terreus* in an inorganic salt solution.

DECOMPOSITION OF XYLAN, CELLULOSE, LIGNIN, AND STRAW BY A SOIL INFUSION IN SOLUTION CULTURES

Three hundred milligrams of carbon as xylan, cellulose, lignin, or oat straw were added to 300 cc of a nutrient solution containing the following:

KH_2PO_4	0.02%
$NaNO_3$	0.2 %
$MgSO_4$	0.02%

The solutions were sterilized at 15 pounds pressure for 30 minutes. The treatments made were the same as those shown on page—. The cultures were incubated 15 days and the carbon dioxide evolved was determined as in the previous experiment. The results obtained are presented in Table 2.

TABLE 2.—*Milligrams of carbon dioxide produced by a soil infusion in solution from various organic constituents.*

Time in hours	Check	Lignin	Xylan	Cellulose	Straw
48	15.9	22.2	20.2	44.8	37.8
69	25.1	32.0	42.6	66.5	71.6
111	48.6	39.0	75.3	81.4	92.3
132	37.5	45.7	100.8	——	112.2
156	47.4	54.5	122.7	125.6	145.5
235	56.4	85.2	189.6	——	192.7
285	63.9	98.5	234.1	203.7	230.4
303	68.7	116.7	256.2	231.3	254.5
315	77.4	123.9	282.2	256.5	282.9
367	90.5	131.2	318.9	287.9	322.1

The data in the table show that with the soil infusion there was a considerable evolution of carbon dioxide in all cultures. Cellulose and straw were decomposed more rapidly at first than the other materials. Apparently, some decomposition of the lignin was brought about by the soil infusion. There was an average of 40.7 mgm more carbon dioxide evolved from the flasks containing the prepared lignin than from the checks. However, by analysis 2.53% of the lignin was unaccounted for, and the oxidation of this material might account for some of this carbon dioxide. On the other hand, assuming the lignin unaccounted for by analysis to contain 50% carbon and that it was completely oxidized to carbon dioxide, only 14.6 mgm carbon dioxide can be accounted for, leaving 26.1 mgm carbon dioxide which presumably resulted from the decomposition of the lignin. This represents, however, a small amount, only about 2.3% of the lignin added.

DECOMPOSITION OF LIGNIN BY *Stereum purpureum* IN SAND CULTURES

The results in the preceding experiments indicate that prepared lignin is quite resistant to aerobic decomposition. However, results obtained in studies on the production of artificial farm manure (3) indicated that natural plant lignin decomposed quite completely. It is possible that in the extraction of lignin the lignin is changed into a form more resistant to decomposition than the natural plant lignin or that after extraction it possesses antiseptic or toxic properties. It is also quite possible that some chemical change in the lignin took place during the fermentation of the compost which rendered the lignin available and then biochemical oxidation took place.

To study this problem three lignin products, namely, "Ca-lignin", "oxidized-lignin", and "Iodo-carboxy-lignin"[4] (4), were prepared, and the rate of decomposition determined as in the preceding experiments.

The "Ca-lignin" was prepared according to the following procedure. A quantity of H-lignin extracted from oat straw was dissolved in concentrated ammonium hydroxide and filtered. A quantity of calcium chloride was dissolved in concentrated ammonium hydroxide and filtered. The two solutions were diluted with cold distilled water (10°C) and then mixed. A brownish-yellow precipitate was obtained which was centrifuged and washed by decantation and centrifuging four times with cold distilled water. The precipitate was then re-suspended in cold distilled water, aerated until free of amonia, and filtered. The "Ca-lignin" was slightly soluble in water. After the aeration the suspension was filtered, dried at a low temperature (50°C), and ground.

The "oxidized lignin" was prepared by treating 2.0 grams of H-lignin with 20 cc of a 1% solution of hydrogen peroxide at room temperature over night. The material was then dried at a low temperature, 50°C.

Duplicate 100-gram samples of pure quartz sand were weighed into 1-liter Erlenmeyer flasks. The materials used as a source of carbon were added in the amount of 0.2 gram and thoroughly mixed with the sand. Thirty cc of an inorganic salt solution containing 0.2% $NaNO_3$, 0.02% K_2HPO_4, and 0.01% $MgSO_4$ were added and the cultures sterilized for one hour at 15 pounds pressure on each of three consecutive days. The flasks were then inoculated with *Stereum purpureum*, placed in the incubator at 28°C, and the amount of carbon dioxide evolved determined at intervals as in the previous experiments. The treatments made and the results obtained after incubation for 115 days are presented in Table 3.

TABLE 3.—*The decomposition of lignin by Stereum purpureum in sand cultures.*

Flask No.	Carbon source	Average mgm CO_2 produced in 115 days	Average increase over check, mgm
1	None	38.5	——
2	H-lignin	85.6	47.1
3	"Ca-lignin"	73.6	35.1
4	"Oxidized-lignin"	111.1	72.6
5	"Iodo-carboxy-lignin"	72.1	33.6
6	Cellulose	61.8	23.5
7	Cellulose + H-lignin	279.3	240.8
8	Xylan	267.9	229.4
9	Xylan + H-lignin	287.8	249.3

The results show that *Stereum purpureum* is able to utilize lignin, xylan, and cellulose extracted from oat straw. Xylan was readily attacked by this organism, whereas H-lignin and cellulose were utilized more slowly. The addition of H-lignin to the cellulose apparently stimulated the decomposition of the cellulose. The "Ca-

[4]By courtesy of Dr. A. W. Walde, Chemistry Department, Iowa State College.

lignin" and the "Iodo-carboxy-lignin" were less readily decomposed by this organism than the H-lignin. Mild oxidation of the H-lignin by treatment with hydrogen peroxide apparently rendered the H-lignin more available to *S. purpureum* or split out compounds from the lignin molecule which could be utilized. If it is assumed that the "oxidized-lignin" contained 50% carbon, which is probably too high, then it was decomposed approximately 30%.

SUMMARY AND CONCLUSIONS

Lignin, xylan, and cellulose were extracted from oat straw and used in comparison with oat straw as sources of carbon for some common soil molds in a series of five experiments. "Ca-lignin" and an "oxidized-lignin" were prepared and used as sources of carbon for comparison with H-lignin for *Stereum purpureum* in a sand culture medium. H-lignin was very resistant to aerobic decomposition but was slightly decomposed by a soil infusion in solution cultures and by *S. purpureum* in a sand culture medium. The "oxidized-lignin" was less resistant to decomposition by *S. purpureum* than H-lignin.

It was concluded that lignin does not possess antiseptic properties and though it may decompose slowly, it gradually disappears from soils.

LITERATURE CITED

1. DE'SIGMOND, A. A. J. Principles and scheme of a general soil system. Soil Res., 3 : 103–127. 1933.
2. PETERSON, C. J., and HIXON, R. M. Chemical Examination of the tissue of cornstalk. Ind. and Eng. Chem., Anal. Ed., 1 : 65. 1929.
3. SMITH, F. B., and BROWN, P. E. The decomposition of straw in the production of artificial manure. Iowa State College Jour. Sci., 8 : 409–413. 1934.
4. WALDE, A. W. The alkaline oxidation of lignin. Thesis, Iowa State College Ames, Iowa. 1933.

THE MINERAL CONTENT OF SOIL TYPES AS RELATED TO "SALT SICK" OF CATTLE[1]

O. C. BRYAN AND R. B. BECKER[2]

HILGARD (16)[3] first pointed out in a systematic way a definite relationship between native vegetation and soil types in North America. While his observations have been confirmed generally by later workers, the relation between soil types and the health of animals grazing thereon has not been defined so clearly. This has been due partly to a lack of refinement in chemical methods and partly to the fact that animals range more widely in their search for food nutrients than is possible with individual plants.

The disease of cattle known as "salt sick" has been an age-old problem in parts of Florida with cattle grazing over certain types of soils. It has been studied intermittently by members of the Florida Agricultural Experiment Station staff for over 40 years. Corrective measures finally were discovered and applied by Becker, Neal, and Shealy (9) in 1930. According to them, salt sick is a nutritional anemia of animals, due to insufficient amounts of copper and iron in the feed. It seems to be associated with certain types of sandy and peat soils on which forage crops contain less iron than do the same class of forages on healthy soil areas. A number of local names are applied to the disease or condition, corresponding to the character of the local ranges where it occurs, namely, scrub sick, hill sick, marsh sick, prairie sick, bay sick, salt sick, and just plain sick.

A condition similar to salt sick of livestock, sometimes called progressive or nutritional anemia and arising from the lack of certain minerals in feeds and soils upon which animals graze, is known to occur in New Zealand (2, 3, 5, 6, 7), southern Scotland (12), Kenya Colony in East Africa (18), and King's Island, Tasmania (13). This disease is known locally as bush sickness in New Zealand, Nakuruitis in Kenya Colony, and vinquish, daising, pining or pine in Scotland, and according to Aston (7), is identical with salt sick of Florida. Although iron supplement in the feed has been a satisfactory curative in many cases, there have been some striking exceptions. This is confirmed by the fact that Becker, *et al.* (9) found it necessary to add small amounts of copper to the iron supplement in correcting the condition with salt sick animals.

Although field surveys (1929) indicated that the salt sick problem in Florida was more prevalent on certain light sandy soils than on heavier soils, no definite correlation of the disease with specific soil types had been established. The object of this investigation was to

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[3]Figures in parenthesis refer to "Literature Cited," p. 127.

determine to what extent soil types and composition of soils influenced the occurrence and distribution of salt sick on Florida ranges.

PLAN OF STUDY

Composite soil samples from at least three separate borings were collected from 21 mineral soils and 2 peat soils, representing typical areas on which range cattle were known to develop salt sick, and from 17 healthy mineral soils on which range cattle were known to remain free from salt sick. These areas had been located by the junior author and co-workers in the Department of Animal Husbandry of the Florida Experiment Station for the purpose of studying the condition in cattle in relation to the composition of range grasses. In all cases virgin soils were collected to a depth of 4 feet and stored in glass jars by foot depths.

After drying, the soils were sieved through cloth screens and ground in an agate mortar to avoid metal contaminations. Standard methods of procedure by acid extraction (4) were used to determine the calcium, phosphorus, and iron. From 5 to 40 grams of soil (80-mesh), depending on clay content, were ignited in a muffle furnace at 450° before digesting with a 1 to 1 solution of hydrochloric acid to which small amounts of nitric acid had been added. The solutions were boiled for 10 minutes and then evaporated on a steam bath until dry. Additional amounts of acid were added and again evaporated to dryness on a steam bath, and the residue taken up in hot solution of dilute hydrochloric acid and stored in volumetric flasks for analysis. This procedure appeared to give complete extraction of the metals in sands. Silt and clay determinations were made by the Bouyoucos method (11).

Since the earlier studies with cattle showed that copper and iron supplements prevented salt sick (9), it was thought desirable to determine these elements in the soils in addition to the calcium and phosphorus. Controls were included in all cases to ascertain the impurities in the reagents. Impurities were found often in determinable amounts even with the best of C. P. reagents. The pyridine method (14) proved to be the most satisfactory procedure for determining copper in soils. It was necessary to remove the iron by double precipitation before determining the copper. Results of these analyses are tabulated in Tables 1 and 2 in conjunction with the soil types. Analyses were made of the third foot of soils, but since they are in the same order as those in the first and second feet, they are not included in the tables. The amount of silt and clay also was determined, and the results included in the tables for comparison.

A preliminary study has been begun of the effects upon the growth of mustard plants obtained by applying amendments to certain of these soils.

RESULTS AND DISCUSSION

Examination of the data in Tables 1 and 2 shows that the salt sick areas consist of sands and fine sands of the Leon, Portsmouth, Dade, and Norfolk series and also peat deposits. The healthy areas consist of fine sandy loams or sands with clay subsoils of the Bladen, Gainesville, Hernando, Fellowship, Orangeburg, Lakewood, and Norfolk series. The soils in the healthy areas contained over twice as much silt and clay (9.9%) as did those in the salt sick areas (4.3%) in the first foot and over three times as much (15.2% as against 4.4%) in the second foot. The Norfolk soils have a wide range of types and phases which vary greatly in texture and natural fertility. This fact

seems to account for this group of soils occurring in both the salt sick and the healthy ranges. The Lakewood sand has a bright yellow sub-

TABLE 1.—*Mineral composition of first foot of Florida soils as related to "salt sick" of cattle.*

Soil type	Calcium %	Phosphorus %	Iron %	Copper, p.p.m.	Silt and clay %	pH values
		"Salt Sick" Areas				
Dade sand	0.109	0.003	0.012	5.71	2.9	6.59
Leon sand	0.040	0.013	0.014	1.96	5.5	4.72
Leon sand	0.021	0.004	0.030	2.43	5.0	4.65
Leon sand	0.022	0.003	0.018	2.01	1.8	4.55
Leon sand	0.021	0.006	0.007	1.61	2.8	4.59
Leon fine sand	0.010	0.006	0.056	4.51	6.0	4.91
Leon sand	0.042	0.005	0.013	3.15	2.2	4.93
Leon sand	0.017	0.004	0.071	5.00	4.3	5.28
Portsmouth sand	0.017	0.014	0.023	7.85	5.4	4.55
Portsmouth fine sand	0.021	0.004	0.011	6.03	4.5	4.41
Portsmouth fine sand	0.121	0.007	0.069	2.87	3.4	6.76
Norfolk fine sand	0.031	0.007	0.054	3.42	7.5	5.07
Norfolk sand	0.041	0.010	0.043	4.62	4.3	5.68
Norfolk fine sand	0.042	0.030	0.067	3.18	8.9	5.46
Norfolk sand	0.027	0.070	0.055	2.81	1.7	4.95
Norfolk fine sand	0.052	0.011	0.086	1.50	3.9	6.00
Norfolk sand	0.026	0.015	0.041	4.49	4.2	4.97
Norfolk fine sand	0.018	0.009	0.026	5.11	3.7	4.85
Norfolk fine sand	0.027	0.018	0.065	5.01	2.8	5.01
Norfolk sand	0.022	0.007	0.061	5.26	5.4	4.98
Norfolk sand	0.025	0.015	0.014	4.84	4.8	5.62
Average	0.036	0.012	0.040	3.97	4.3	5.17
		Healthy Areas				
Bladen fine sand	0.025	0.008	0.124	5.05	4.9	5.00
Bladen fine sand	0.037	0.003	0.134	11.52	10.7	5.19
Fellowship sandy loam	1.789	0.331	1.266	18.10	25.2	5.68
Gainesville fine sand	0.052	0.008	0.203	4.21	6.0	5.37
Hernando sandy loam	0.206	0.070	0.544	5.07	7.6	6.19
Hernando sand	0.041	0.005	0.082	6.98	5.0	4.93
Lakewood sand	0.019	0.009	0.077	2.42	1.1	5.40
Norfolk loamy sand	0.072	0.114	0.555	7.39	15.6	5.33
Norfolk fine sand	0.042	0.005	0.232	8.37	6.4	4.84
Norfolk sand	0.020	0.005	0.112	10.47	7.6	5.54
Norfolk fine sand	0.050	0.005	0.077	7.19	7.1	4.66
Norfolk fine sand	0.030	0.009	0.079	8.10	7.0	4.87
Norfolk fine sand	0.034	0.003	0.141	20.97	10.4	5.03
Orangeburg loamy sand	0.106	0.015	0.768	6.46	15.6	5.03
Orangeburg fine sandy loam	—	0.178	1.445	9.36	19.3	5.10
Orangeburg fine sand	0.055	0.040	0.601	5.74	7.6	5.46
Ruston loamy sand	0.014	0.156	0.733	8.20	10.6	5.34
Average	0.162	0.057	0.422	8.56	9.9	5.24
		"Salt Sick" Areas on Peat				
Peat	3.398	0.029	0.743	42.30	—	5.74
Peat	1.079	0.025	0.277	12.75	—	4.68
Average	2.239	0.027	0.510	27.53	—	5.27

soil with a higher content of iron than do most of the other sands, but a rather low content of silt and clay, as shown in the tables. This

TABLE 2.—*Mineral composition of second foot of Florida soils as related to "salt sick" of cattle.*

Soil type	Calcium %	Phosphorus %	Iron %	Copper, p.p.m.	Silt and clay %	pH values
"Salt Sick" Areas						
Dade sand	0.261	0.006	0.183	0.27	3.4	7.43
Leon sand	0.011	0.004	0.038	0.81	5.2	4.35
Leon sand	0.006	0.001	0.026	0.37	4.6	5.41
Leon sand	0.001	0.008	0.014	0.86	2.0	5.18
Leon sand	0.006	0.002	0.017	0.22	3.8	5.84
Leon fine sand	0.002	0.003	0.184	1.40	4.8	4.66
Leon sand	0.150	0.002	0.008	0.66	2.4	5.72
Leon sand	0.008	0.003	0.026	1.29	4.4	4.95
Portsmouth sand	0.008	0.013	0.047	0.27	3.6	4.76
Portsmouth fine sand	0.003	0.002	0.008	0.93	4.6	5.04
Portsmouth fine sand	0.086	0.002	0.029	0.72	1.6	6.17
Norfolk fine sand	0.004	0.003	0.124	1.44	7.6	5.09
Norfolk sand	0.006	0.008	0.050	1.85	3.8	5.55
Norfolk fine sand	0.006	0.004	0.124	1.69	8.4	5.32
Norfolk sand	0.016	0.011	0.065	0.81	4.4	5.06
Norfolk fine sand	0.001	0.004	0.101	2.00	3.4	5.42
Norfolk sand	0.003	0.007	0.053	1.22	5.2	5.23
Norfolk fine sand	0.002	0.004	0.047	1.32	4.4	5.16
Norfolk fine sand	0.013	0.018	0.107	0.84	3.0	5.52
Norfolk sand	0.005	0.009	0.091	1.65	7.0	4.96
Norfolk sand	0.016	0.013	0.161	1.81	5.2	5.29
Average	0.029	0.006	0.072	1.07	4.4	5.27
Healthy Areas						
Bladen fine sand	0.006	0.004	0.160	2.02	5.0	4.60
Bladen fine sand	0.036	0.002	0.842	1.66	21.6	5.13
Fellowship sandy loam	1.085	2.687	2.508	6.20	—	5.31
Gainesville fine sand	0.011	0.045	1.899	5.96	27.2	4.58
Hernando sandy loam	0.102	0.190	0.972	2.34	16.0	5.37
Hernando sand	0.066	0.004	2.514	2.95	15.6	5.55
Lakewood sand	0.001	0.008	0.177	0.58	1.6	4.90
Norfolk loamy sand	0.007	0.060	0.675	6.73	11.4	4.71
Norfolk fine sand	0.016	0.013	0.714	7.04	10.6	5.34
Norfolk sand	0.029	0.004	0.180	3.35	7.2	5.11
Norfolk fine sand	0.011	0.002	0.156	1.39	7.0	5.53
Norfolk fine sand	0.008	0.010	0.204	1.22	7.4	5.16
Norfolk fine sand	0.009	0.013	0.356	1.61	14.2	4.61
Orangeburg loamy sand	0.041	0.002	5.506	3.76	48.4	4.55
Orangeburg fine sandy loam	0.021	0.061	1.791	2.85	26.8	5.41
Orangeburg fine sand	0.190	0.050	0.723	11.11	8.8	5.09
Ruston loamy sand	0.020	0.050	0.792	3.31	15.0	5.23
Average	0.098	0.189	1.186	3.77	15.2	5.07
"Salt Sick" Areas on Peat						
Peat	0.714	0.012	0.740	26.68	—	6.75
Peat	1.074	0.022	0.401	2.72	—	5.53
Average	0.894	0.017	0.571	14.70	—	6.20

higher content of iron seems to account for this type being in the healthy group of range soils.

In general, the results show that the healthier soils contained higher amounts of silt and clay regardless of series, but in no case examined were the Leon and Portsmouth sands and fine sands in the healthy areas. These results seem to be in agreement with those of New Zealand regarding soil texture (5). Both areas of peat examined were subject to salt sick.

The data in Tables 1 and 2 also show some interesting correlations between the amount of mineral matter in the salt sick areas as compared with the healthy areas. The surface foot of healthy range soils contained an average of 0.162% of calcium, 0.057% of phosphorus, 0.422% of iron, and 8.56 p. p. m. of copper, while the salt sick soils contained 0.036% of calcium, 0.012% of phosphorus, 0.040% of iron, and 3.97 p. p. m. of copper.

While the results are not always consistent from soil to soil, the average results are rather positive. The surface foot of the soils of the healthy range areas contained approximately 10 times as much iron, 2 times as much copper, and 5 times as much calcium and phosphorus as did the soils from the salt sick areas. With few exceptions, the salt sick soils contained less copper and iron than did the healthy range soils. It may be noted that all of these soils are low in calcium and phosphorus, with one or two exceptions. The content of iron increased from the first to the second foot, but that of calcium and phosphorus decreased on the salt sick areas. At the same time that the phosphorus decreased on the salt sick areas it increased on the healthy areas. This may be explained on the assumption that the greater part of the iron existed in the clay or mineral portion of the soil, while the calcium and copper were more concentrated in the organic matter. Both of the peat soils contained comparatively high amounts of copper and iron. These peat soils were not subject to overflow from healthy range areas.

The results of this study, together with those of Neal and Becker (17), indicate that the composition of the soil has a definite influence on the composition of plants. This has been borne out by the work in New Zealand (2, 5) with soils on which bush sickness develops.

It is interesting to point out that the soils of Florida contain less iron than do those from New Zealand. It is also significant that Florida soils contain less calcium and phosphorus than do the New Zealand soils, according to the hydrochloric acid extraction method. No reports of copper were made on the soils from these other countries. In most cases, the New Zealand soils (5) contain several times more available iron (citric acid extract) than that of the total content in the salt sick soils of Florida. It appears that the iron in mineral soils of Florida is more available to plants than is the case with the soils of New Zealand. Results obtained by Allison, *et al.* (1) show that copper is not available on the raw peat soils of the Florida Everglades.

It is possible that the acid extraction method may show slightly lower results than does the fusion method. However, it is extremely doubtful whether the differences would be significant with marine sands which possess such a low content of silt and clay.

From the results of this study, it would be reasonable to assume that the St. Lucie, St. Johns, and Plummer soils would be subject to salt sick in cattle. Moreover, the results explain the observations and practices of cattlemen in different areas of the state. They have found it necessary for years to transfer salt sick animals to healthy ranges, sometimes known locally as "hospital" lands, in order to avoid loss. Where this practice was observed, the so-called hospital lands have been either on sandy loam or on one with a sandy clay strata from 15 to 30 inches below the surface. These healthy soils contained more iron and other minerals than did the deep sands, and according to Neal and Becker (17), vegetation growing on these healthy range soils contained more iron than did that on the salt sick areas.

The fact that salt sick occurs on both calcareous and low-lime soils bars it from being related to calcium deficiency. However, highly calcareous soils often reduce the solubility of the iron and thereby may tend to induce salt sick sooner. This is confirmed by observations in New Zealand (5). It is possible that the low content of phosphorus and calcium in the soil hinders normal plant development and that the incidence and severity of salt sick among animals may be modified by the general plane of nutrition which involves elements other than copper and iron. Salt sick areas are known to overlap onto areas where cattle also suffer from phosphorus deficiency (8, 9).

APPLICATION OF SOIL AMENDMENTS

Since the soils on which cattle were known to develop salt sick contained less copper than did those on healthy areas, it was thought advisable to determine the effects on the response of plants obtained by adding copper salts to these soils under controlled conditions. Mustard was chosen as an index plant for this purpose because of its rapid habits of growth and the ease of handling it under greenhouse conditions.

Uniform amounts of a virgin soil from a healthy range area and similar amounts representing a salt sick area were placed in 2-quart glazed earthenware jars in the greenhouse. These soils were then given uniform treatment of a complete fertilizer, including iron, manganese, and zinc. Copper sulfate was added in amounts varying from 0.5 to 10 p. p. m., and the soils planted to mustard. They were moistened with tap water as needed and the plants allowed to grow. The relative amounts of mustard on the two soils at the end of 40 days are shown in Fig. 1.

It may be observed from the rates of growth of the mustard plants on the Leon sand—a salt sick soil—that there was a decided response to the copper treatments, while very little response was noted on Gainesville fine sand—a healthy range soil. These results further support the data in Tables 1 and 2 in that the salt sick soils are deficient in copper even for the growth of certain plants. A number of other soils were treated for copper and iron stimulation, the results of which are being reported in a separate paper.

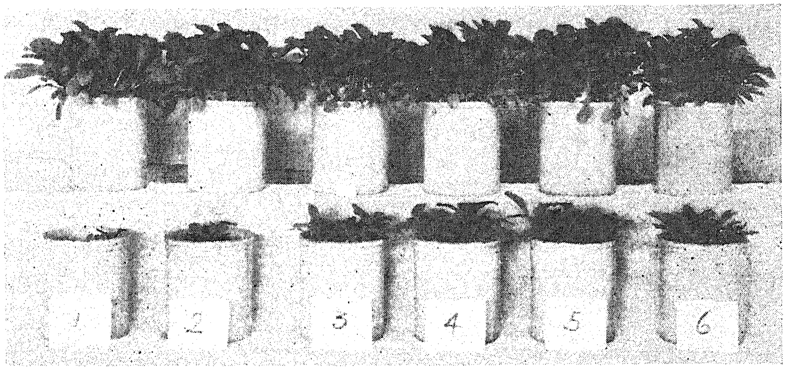

FIG. 1.—The effect of copper sulfate on a "salt sick" soil.

Upper, Gainesville fine sand, a healthy soil; *lower*, Leon sand, a "salt sick" soil. Culture No. 1 received no copper; cultures Nos. 2, 3, 4, 5, and 6 received 0.5, 1, 2, 5, 5, and 10 p.p.m., respectively, of copper sulfate on both soils; all other factors held constant.

SUMMARY

A study was made of 40 range soils of Florida, 21 of which were mineral soils and 2 organic soils on which cattle were known to develop salt sick. Seventeen were mineral soils on which cattle were known to remain healthy. These soils were classified into types and analyzed for total calcium, phosphorus, iron, and copper. Some of the representative soils were treated with varying amounts of copper sulfate and planted to mustard.

The results may be summarized as follows:

1. The salt sick soils consisted of sands and fine sands of the Leon, Portsmouth, Dade, and Norfolk series.

2. The healthy range soils consisted of the sandy loams and sands of the Bladen, Fellowship, Hernando, Gainesville, and Orangeburg soils, and also the Norfolk soils with sandy loam or clay subsoil.

3. The surface soil of the healthy ranges contained approximately 10 times as much iron, 2 times as much copper, 5 times as much phosphorus, and 5 times as much calcium as did those of the salt sick areas.

4. The organic soils contained relatively higher amounts of calcium, iron, and copper than did the mineral soils, yet they were subject to salt sick.

5. Cattle will develop salt sick on soils with 0.036% of iron and 3.85 p. p. m. of copper, while they remain healthy upon soils with 0.42% of iron and 8 p. p. m. of copper.

6. Additions of copper sulfate to the salt sick soils increased the growth of mustard under controlled conditions.

LITERATURE CITED

1. ALLISON, R. V., BRYAN, O. C., and HUNTER, J. H. The stimulation of plant responses on the raw peat soils of the Florida Everglades through the use of copper sulfate and other chemicals. Fla. Agr. Exp. Sta. Bul. 190 : 35–80. 1927.
2. ASKEW, H. O., and RIGG, T. Bush sickness. Investigations concerning the occurrence and cause of bush sickness in New Zealand. New Zeal. Dept. Sci. and Ind. Res. Bul. 32 : 5–62. 1932.
3. ———— and RIGG, T. Sheep-sickness in the Pakawau District of the Collingwood County, Nelson. New Zeal. Jour. Sci. and Tech., 15 : 305–308. 1934.
4. Association of Official Agricultural Chemists. Official methods of analysis. Compiled by the Committee of Editing Methods of Analysis. Revised to July 1, 1924. Washington, D. C. 1925.
5. ASTON, B. C. The bush sickness investigation. Laboratory work and results. New Zeal. Jour. Agr., 28 : 301–305; 381–390; 29 : 14–17. 1924.
6. ————. Cure of iron starvation (bush sickness) in stock. New Zeal. Jour. Agr., 38 : 232–237. 1929.
7. ————. Recent work on iron starvation in other countries. New Zeal. Jour. Agr., 43 : 270–272. 1931.
8. BECKER, R. B., NEAL, W. M., and SHEALY, A. L. Stiffs or sweeny (phosphorus deficiency) in cattle. Fla. Agr. Exp. Sta. Bul. 264 : 3–27. 1933.
9. ————, ————, ————. I. Salt sick: Its cause and prevention. II. Mineral supplements for cattle. Fla. Agr. Exp. Sta. Bul. 231 : 5–23. 1931.
10. ————, ————, ————. A natural copper deficiency in cattle rations. Science, 74 : 418–419. 1931.
11. BOUYOUCOS, GEORGE J. The hydrometer method for studying soils. Soil Science, 25 : 365–371. 1928.
12. GREIG, J. R., DRYERRE, H., GODDEN, W., CRICHTON, A., and OGG, W. G. Pine: A disease affecting sheep and young cattle. Vet. Jour., 89 : 99–110. Also Scot. Jour. Agr., 16 : 298–303. 1933.
13. DICKINSON, C. G. King Island "coasty" disease. Aust. Vet. Jour., 3 : 82–85. 1927.
14. ELVEHJEM, C. A., and LINDOW, C. W. Determination of copper in biological materials. Jour. Biol. Chem., 81 : 435–443. 1929.
15. GODDEN, W., and GRIMMETT, R. E. R. Factors affecting the iron and manganese content of plants with special reference to herbage causing pining and bush-sickness. Jour. Agr. Sci., 18 : 363–368. 1928.
16. HILGARD, E. W. Soils. New York: Macmillan Company. 1905.
17. NEAL, W. M., and BECKER, R. B. The composition of feedstuffs in relation to nutritional anemia in cattle. Jour. Agr. Res., 47 : 249–255. 1933.
18. ORR, J. B., and HOLMS, A. The mineral deficiencies of pastures in Kenya Colony and their effects on grazing animals. (Gr. Brit.) Economic Advisory Council Com. on Mineral Content of Natural Pastures. Rpt. 6 : 22–23, 43–48, and 52–53. 1931.
19. PERSONS, A. A. A chemical study of some typical soils of the Florida peninsula. Fla. Agr. Sta. Bul. 43 : 601–714. 1897.
20. RIGG, T., and ASKEW, H. O. Soil and mineral supplements in the treatment of bush-sickness. Empire Jour. Exp. Agr., 2, No. 5 : 1–8. 1934.

THE EFFECTS OF INOCULATION AND FERTILIZATION OF SPANISH PEANUTS ON ROOT NODULE NUMBERS[1]

J. F. DUGGAR[2]

EXAMINATION of Spanish peanut plants growing on a number of farms in the eastern and central parts of Alabama showed a surprisingly small number of root nodules. Hence experiments were made in 1930, 1931, and 1932 with Spanish peanuts to ascertain whether such scant nodulation would continue under known conditions and whether it would be corrected by artificial inoculation of seed or by the application of certain well-known fertilizers. The main objectives have been to determine to what extent inoculation and fertilization would affect the number of nodules per plant and to ascertain to what extent an increase in nodule numbers through inoculation or fertilization would influence yields of Spanish peanuts.

METHODS AND CONDITIONS

In the experiments here reported unhulled Spanish peanuts were planted on Norfolk soils about 2 miles south of Auburn, Ala. Artificial inoculation was effected by soaking the unhulled seeds for about an hour in a suspension of pure cultures made from peanut nodules. The fertilizer was drilled about 3 inches deep; and, unless otherwise stated, it was carefully mixed with the soil to avoid immediate contact with the planted peanuts. Counts of nodules were made at intervals on many plants, which were collected from a number of scattered locations on each plat.

In the counts made in the latter part of the growing season it was practicable to determine, in addition to the number of total nodules, also the number of large nodules. The latter were arbitrarily taken as those nodules having a maximum diameter equal to or greater than that of an average matured seed of hairy vetch.

In the summer of 1932 the rainfall was ample, but in 1930 and 1931 periods of severe drought occurred.

RESULTS

EFFECTS OF ARTIFICIAL INOCULATION

Table 1 shows the number of nodules, both total and large, on unfertilized Spanish peanut plants at successive dates in 1930, 1931, and 1932.

Nodules of all sizes were relatively much more abundant on the plants grown from inoculated than on those from untreated seed. This held true for at least 18 out of the 19 comparisons shown in the above table. Without artificial inoculation, unfertilized, nearly mature Spanish peanut plants averaged scarcely eight *total* nodules and fewer than three *large* nodules. That such few nodules were insufficient for optimum growth of the plant is indicated by generally low yields of both mature nuts and entire dry plants.

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[1]Contribution from the Department of Special Investigations, Alabama Agricultural Experiment Station, Auburn, Ala. Received for publication December 10, 1934.

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TABLE 1.—*Number of root nodules per peanut plant, with and without inoculation, in 1930, 1931, and 1932.*

Date of planting	Average number of nodules at plant age of									
	22–23 days		27–32 days		41–48 days		67–85 days		106–113 days	
	No inoculation	Inoculated	No inoculation	Inoculated	No inoculation	Inoculated	No inoculation	Inoculated	No inoculation	Inoculated
Average Number of Total Nodules per Plant										
June 12, 1930	0.1	1.1	0.3	1.9	2.9	7.5	10.6	14.2	10.9	28.4
July 11, 1931	0.8	7.1	3.2	7.2	—	—	11.3	8.8	7.1	13.0
May 24, 1932	0.4	1.4	—	—	0.4	13.2	3.6	23.7	5.7	51.2
3-year av.	0.4	3.2	1.7*	4.5*	1.6*	10.4*	7.5	15.6	7.9	30.9
Average Number of Large Nodules per Plant										
June 12, 1930	—	—	—	—	—	—	1.1	9.5	2.7	10.9
July 11, 1931	—	—	—	—	—	—	3.1	4.6	1.5	5.7
May 24, 1932	—	—	—	—	—	—	0.3	10.5	2.4	19.8
3-year av.	—	—	—	—	—	—	1.5	8.2	2.2	12.2

*Average for 2 years.

EFFECT OF INOCULATION ON NODULE NUMBERS AND YIELDS FOLLOWING VARIED FERTILIZATION

In 1930, inoculation of unhulled Spanish peanut seed intensified nodulation and was followed by an increase of 16% in yield of nuts per plant. In 1931, the increase in yield of nuts ascribed to artificial inoculation alone, with its increased nodulation, was 71% on the unfertilized series and 20% on the series of plats that received basic slag. The unweighted average for 3 years showed a gain from inoculation with peanut cultures of 40% in yield of nuts per plant in the absence of any fertilizer.

Table 2 shows the average number of nodules per plant at the final harvest in 1932, and the yields of dry nuts per plant where various fertilizers had been drilled in and mixed with the soil just before planting unhulled Spanish peanuts, both with and without inoculation.

TABLE 2.—*Numbers of nodules at harvest and yields of inoculated and non-inoculated Spanish peanut plants receiving different fertilizer treatments in 1932.*

Fertilizer, lbs. per acre	Total nodules per plant		Large nodules per plant		Yield of dry nuts, grams per plant		Increase in yield from inoculation, %
	Not inoculated	Inoculated	Not inoculated	Inoculated	Not inoculated	Inoculated	
None	5.7	51.2	2.4	19.2	10.0	13.4	33
600 lbs. basic slag phosphate	4.7	62.0	1.7	22.6	10.8	16.7	54
400 lbs. superphosphate	9.0	65.1	3.6	19.3	11.9	16.7	40
400 lbs. hydrated lime	13.7	70.3	6.1	18.1	17.7	19 0	7
50 lbs. muriate of potash, 400 lbs. hydrated lime, and 600 lbs. basic phosphate	13.7	84.1	8.1	41.2	17.4	20.2	16
50 lbs. sulfur, 400 lbs. hydrated lime, and 600 lbs. basic slag phosphate	7.0	61.6	2.1	22.3	13.9	17.9	29
Av. of 6 conditions	9.0	65.7	4.0	23.8	13.6	17.3	30

Inoculation of unhulled seed resulted in a very large increase in nodule numbers, regardless of fertilization. Inoculation afforded, on the average, a six-fold increase in total nodules, a five-fold increase in large nodules, and a 30% increase in yield of nuts.

In the favorable season of 1932 each of the fertilizers significantly increased the yields of dry nuts where the fertilizer did not come into immediate contact with unhulled seed.

EFFECT ON NODULATION AND YIELD FROM CONTACT BETWEEN FERTILIZERS AND SEED PEANUTS

It seemed desirable to ascertain what effects, if any, on nodule numbers and yields would result if the fertilizers should be so applied as to come into immediate contact with the seed, as might occur to some extent in careless farm practice. The fertilizers were separately drilled in uncovered furrows, but on top of and in immediate contact with the unhulled seed, and at the same rates as in the preceding experiments. The contact between seed and fertilizer was further raised to the maximum by a pre-planting treatment consisting of wetting the unhulled nuts with tap water and then rolling them in a small part of the appropriate fertilizer.

Most of the chemicals when thus applied caused significant reductions in final nodule numbers and yields. Leading in depressive effect on nodule numbers were separate applications of superphosphate and muriate of potash when thus wrongly placed. Also distinctly depressive to nodule numbers were misplaced land plaster and 100 pounds per acre of manganese sulfate. Hydrated lime so used seemed either slightly depressive or without significant effect. Even basic slag in close contact with unhulled seed in the dry summer of 1931 failed to exercise a favorable effect on nodulation or yield. Most chemicals that notably depressed nodule numbers also reduced the yield of dry nuts per plant. Such unfavorable effects of misplaced fertilizers were in direct contrast with the favorable effects from certain fertilizers properly placed, as discussed in earlier paragraphs.

CORRELATION BETWEEN NUMBERS OF NODULES AND YIELDS OF SPANISH PEANUTS

Both in 1931 and 1932 the average numbers of nodules on Spanish peanut plants were found under most conditions to be significantly and positively related to the average yield of nuts per plant. The correlation coefficient expressing this relationship between number of *total* nodules at harvest time and yield of dry nuts was calculated as $+ .43 \pm .114$ for the averages from each of the 23 variously treated plats planted in May, 1931, and as $+ .68 \pm .096$ for those of the plats variously fertilized in 1932.

Significant and positive were also the relationships between average nut yields and numbers of total nodules that had been found on the blooming plants 49 and 38 days before the final harvest, following varied fertilization and seed treatment. In 1931, the correlation coefficient for total nodules 49 days before harvest in relation to final yields of nuts was $+ .64 \pm .083$. In 1932, it was $+ .65 \pm .099$ for the total nodules as found 38 days before harvest. Thus, in both years, nodule numbers as counted weeks before digging the crop served as rough indications of the relative prospective yields.

In Table 3 are shown the correlation coefficients between nodule numbers at the final harvest date in 1932 and the corresponding average yields of nuts on the *inoculated* plants variously fertilized without contact between seed and fertilizers.

TABLE 3.—*Correlation coefficients showing relation at date of harvest between average number of nodules (total and large) per inoculated plant, variously fertilized, and average yield of dry unhulled peanuts per plant, 1932.*

Fertilizer, lbs. per acre	Number of plants	Coefficient for total nodules and yield	Coefficient for large nodules and yield
None	35	+0.60±.073	+0.59±.040
600 lbs. basic slag phosphate	29	+.30±.113	+.48±.096
400 lbs. superphosphate in drill	36	+.49±.027	+.72±.042
400 lbs. superphosphate near surface	32	+.42±.089	+.61±.035
400 lbs. hydrated lime	24	+.42±.113	+.58±.081
400 lbs. hydrated lime and 600 lbs. basic slag phosphate	37	+.42±.091	+.54±.083
50 lbs. muriate of potash, 400 lbs. hydrated lime, and 600 lbs. basic slag phosphate	33	+.43±.095	+.82±.018
50 lbs. sulfur, 400 lbs. hydrated lime, and 600 lbs. basic slag phosphate	36	+.64±.066	+.77±.045

For each of the plats in the inoculated series the correlation between numbers of *large* nodules per plant and yields of nuts was invariably high and positive and was only moderately altered by the character of the fertilization. This correlation was highest (+ .82 ± .018) on the plants receiving a mixture of potash, lime, and basic slag phosphate.

Generally significant, but somewhat less close, was the relationship on the inoculated series between number of *total* nodules and yield of peanuts.

When nodule numbers were severely restricted by the absence of artificial inoculation, the only correlation coefficient that appeared to be significant was that for the plants receiving a mixture of potash, lime, and basic slag phosphate. This was + .53 ± .092 for total nodules and + .53 ± .091 for large nodules in relation to yield of nuts.

In brief, the correlation data for 2 years indicated that yields of dry nuts per plant tended to increase as numbers of either total or large nodules increased, both as determined at harvest and at a somewhat earlier date. In each year some exceptions occurred where highly unfavorable conditions for plant growth were encountered, including extreme drought and very late planting.

SUMMARY

Spanish peanut plants were found in experiments at Auburn and also on certain sandy soils elsewhere outside of the commercial peanut belt to develop naturally only a scant supply of root nodules.

Artificial inoculation of unhulled seed resulted in large increases in the numbers of both total and large nodules and in average increases of 40 and 30% in yield of nuts per plant.

Artificial inoculation increased nodule numbers and yields in the presence of nearly all of the common fertilizers tested when they did

not come in contact with the unhulled seed. On the other hand, most common fertilizers when applied in *maximum* contact with the unhulled seed in a dry summer reduced the number of total and large nodules and the yields of nuts.

Significant positive correlation was generally found between numbers of either total or large nodules per plant and yield of dry peanuts per plant where conditions were favorable for crop growth. This held true both for numbers of nodules present at the final harvest and also for the numbers found several weeks earlier.

TOXICITY OF SEVERAL CHEMICALS TO A SPECIES OF MOSS COMMON TO OLD PASTURES IN THE NEW ENGLAND STATES[1]

A. B. BEAUMONT[2]

RECENTLY, the writer (1)[3] called attention to the toxicity of sodium nitrate to a species of moss (*Polytrichum commune* L) found in upland pastures of Massachusetts. This species is one of the last to appear in the natural succession of pasture plants concurrent with the depletion of plant nutrients from the soil.

PLAN OF EXPERIMENT

In order to study the effect of other materials on this species of moss, a series of small plats was laid out in the spring of 1931. The plat treatments are listed in Table 1, and those numbered 1 to 9, inclusive, constitute series 1. These plats received nitrogen materials in quantities to supply 30 pounds and 60 pounds of nitrogen per acre, respectively, and the other materials were applied in chemically equivalent amounts. The effects of the materials of series 1 soon indicated that the different ions of the compounds used were more or less specific in their toxic action on haircap moss. Therefore, in 1932, a second series of plats (treatments 10 to 17, inclusive) was laid out adjacent to or near the first series, for the purpose of studying other ionic combinations. All plat treatments were duplicated. Plats of series 1 were 10 by 10 feet and those of series 2, 5 feet by 10 feet. Treatment of all plats was omitted in 1933 but was repeated in 1934. Therefore, plats of series 1 received three applications of materials and those of series 2 received two applications in the period of 1931 to 1934. At the beginning of the experiment the areas treated had a ground vegetation cover consisting of 85% to 95% haircap moss and small percentages of bent grasses, Kentucky bluegrass, "poverty" grass, hard hack (*Spiraea tomentosa* L), running cinquefoil (*Potentilla canadensis* L), and other weeds. The soil is a well-drained glacial till classed as Cheshire fine sandy loam, stony phase.

RESULTS AND DISCUSSION

In the fall of 1934 an estimate of the percentage of eradication of haircap moss was made and samples of soil taken for laboratory studies. The average percentage eradication of moss for each treatment is given in Table 1.

It is apparent that wide differences in the degree of eradication of the moss were obtained. Eradication was greater with the larger amount of material used in every case, but with few exceptions practically the same order prevailed among materials used. Sodium nitrate was the most effective material used, but a strict comparison between this material and those of series 2 is not possible because of the difference in the number of applications made. No significant difference in the effect of the Chilean and synthetic nitrates was ob-

[1]Contribution from the Department of Agronomy, Massachusetts State College, Amherst, Mass. Contribution No. 210, Massachusetts Agricultural Experiment Station. Received for publication December 8, 1934.

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[3]Figures in parenthesis refer to "Literature Cited," p. 137.

TABLE 1.—*Percentage eradication of moss and reaction of soil.*

Plat No.	Treatment	30-lb. nitrogen equivalent				60-lb. nitrogen equivalent			
		Eradication		Soil reaction		Eradication		Soil reaction	
		%	Rank	pH	Rank	%	Rank	pH	Rank
1	Ammonium sulfate (synthetic)	18	9	4.65	2	60	7	4.3	1
2	Calcium cyanamide (Cyanamid)	13	10	4.8	4	65	6	4.7	4
3	Calcium nitrate	8	12	4.8	4	35	9	4.8	5
4	Sodium nitrate (Chilean)	63	2	4.95	6	93	2	5.2	9
5	Sodium nitrate (synthetic)	65	1	4.9	5	95	1	5.15	8
6	Potassium chloride	40	6	4.6	1	93	2	4.8	5
7	Potassium nitrate	30	8	4.9	5	88	4	5.1	7
8	Sodium chloride	50	5	4.6	1	93	2	4.6	2
9	Urea	0	14	4.6	1	13	13	4.6	2
10	Ammonium carbonate	0	14	4.6	1	20	10	4.8	5
11	Ammonium chloride	55	4	4.6	1	90	3	4.7	4
12	Ammonium nitrate	3	13	4.7	3	18	11	4.65	3
13	Potassium carbonate	35	7	4.8	4	70	5	4.9	6
14	Potassium sulfate	10	11	4.9	5	55	8	4.8	5
15	Sodium acetate	60	3	5.0	7	93	2	5.6	11
16	Sodium carbonate	30	8	5.3	8	93	2	5.55	10
17	Sodium sulfate	8	12	4.7	3	15	12	4.7	4
18	Check (1–9)	—	—	4.6	1	—	—	4.6	2
19	Check (9–11)	—	—	4.8	4	—	—	4.8	5

tained. Generally, sodium compounds were the most effective in elimination of the moss, followed in order by compounds of potassium, calcium, and ammonium, but the specific effectiveness of a given compound depended on its anion as well. From the results obtained the ions of the compounds used in more than one combination are tentatively grouped in respect to their eradicating power as follows:

$$\mathrm{Na} \rangle\ \mathrm{K} \rangle\ \mathrm{Ca} \rangle\ \mathrm{NH_4}$$
$$\mathrm{NO_3} \rangle\ \mathrm{Cl} \rangle\ \mathrm{SO_4} \rangle\ \mathrm{CO_3}$$

This arrangement of ions suggests the lyotropic series. With some exceptions, eradicating power of combinations of ions agreed with the order given. Not all possible combinations of the above ions were used in the experiments here reported, but those combinations not used have been used in other pasture experiments in recent years. In other experiments calcium sulfate and calcium carbonate have shown no direct toxic action on haircap moss. In Table 2 materials used in the present experiment are grouped according to their eradicating power, and calcium sulfate and calcium carbonate would fall in the "low" group, as would superphosphate also.

As has been pointed out in a previous (2) paper, the toxic action on haircap moss here considered is direct and should not be confused with the indirect eradication of this plant by competitive crowding. Under the influence of certain fertilizer materials, themselves innoc-

uous to haircap moss, certain grasses, clovers, and other vegetation will in time eliminate this moss by crowding. Directly toxic materials, such as sodium and potassium nitrates and chlorides, more or less immediately kill the moss, as is evident by the presence of large areas of the dead material some time after the application of the salts. In the experiments here considered the vegetation which eventually replaced the moss consisted largely of bent grasses. Only in the case of treatments with sodium carbonate and sodium acetate did any considerable proportion of weeds replace the moss.

TABLE 2.—*Fertilizer materials and other chemicals grouped according to their power of eradicating haircap moss.*

30-lb. N equivalent	60-lb. N equivalent
High Eradicating Power	
Sodium nitrate (Chilean)	Sodium nitrate (synthetic)
Sodium nitrate (synthetic)	
Sodium acetate	
	Sodium nitrate* (Chilean)
	Sodium chloride
Ammonium chloride	Potassium chloride
	Sodium carbonate
	Sodium acetate
Sodium chloride	Ammonium chloride
	Potassium nitrate
Medium Eradicating Power	
Potassium chloride	Potassium carbonate
Potassium nitrate	Calcium cyanamide
Potassium carbonate	Ammonium sulfate
Sodium carbonate	Potassium sulfate
Ammonium sulfate	
Calcium cyanamide	
Low Eradicating Power	
Potassium sulfate	Calcium nitrate
Sodium sulfate*	Ammonium carbonate
Calcium nitrate	Ammonium nitrate
Ammonium nitrate	Sodium sulfate
Ammonium carbonate*	Urea
Urea	

*Bracketed compounds ranked equally in eradicating power.

In a preliminary study of the cause of the toxic effects here reported, consideration was given the effect of the materials used on the soil reaction. Samples of soil were drawn in the fall of 1934 and tested for reaction with the quinhydrone electrode. The pH values for the different treatments are given in Table 1. It may readily be seen that there is no direct correlation between the eradicating power of the materials used and the soil reaction induced by them. For example, in the larger amount ammonium sulfate produced the most acid soil, but it ranked in the middle group as an eradicator of moss; sodium chloride and urea had no effect on soil reaction, but the former ranked high and the latter low in eradicating power; sodium nitrate, sodium carbonate, and sodium acetate were high in eradicating power and raised the reaction of the soil considerably, but in an adjacent experi-

ment where 6,960 pounds of ground limestone had been applied within 10 years and the reaction of the soil had been raised to pH 6.2, haircap moss was abundant.

It appears that the explanation of the ecological relationships of haircap moss revealed by these experiments must be sought primarily in the physiology of the plant. Most likely, absorption and adsorption of ions by the colloidal complex of the soil and the selective absorption of ions by plants play an important rôle in the effect of the materials used. Ions in certain combinations may be innocuous, while in other combinations they may be quite toxic, due to strong absorption by plants or by the soil, or to disappearance of the companion ion through leaching, or in some other way.

Garjeanne (3) has pointed out that some bryophytes prefer nitrogen as NO_3 while others prefer it is NH_4. Richards (4) has called attention to the fact that "mosses in general strongly avoid salt water. None live in the sea and few can be called true halophytes". These ecological facts may contribute ultimately to an explanation of results reported in this paper.

SUMMARY

The toxicity of 17 chemical compounds, including several common nitrogen and potassium fertilizers and sodium salts, to haircap moss (*Polytrichum commune* L) was studied by field tests. This species of moss is common in New England upland pastures, and is one of the last species to appear in the natural succession of plants on soils of depleted fertility.

It was found that the toxicity of the materials used varied with their ionic combinations. The ions were toxic in the following order: Cations, Na〉 K〉 Ca〉 NH_4; anions, NO_3〉 Cl〉 SO_4〉 CO_3.

No correlation was found to exist between the eradicating power of the materials used and the soil reaction induced by them.

The explanation of the effect of the different materials probably lies in the physiological requirements of the moss. Selective absorption by growing plants, fixation by the soil colloidal complex, and chemical and biological changes of materials applied probably play an important rôle in the net results produced in the field.

LITERATURE CITED

1. BEAUMONT, A. B. Toxicity of sodium nitrate for a species of moss. Science, 75: 312–313. 1932.
2. ————. Experiments with permanent pastures. Mass. Agr. Exp. Sta. Bul. 281. 1932.
3. GARJEANNE, A. J. M. Manual of Bryology. Edited by Martinus Nyhoff, the Hague. 1932. (Page 216.)
4. RICHARD, P. W. Manual of Bryology. Edited by Martinus Nyhoff, the Hague. 1932. (Page 384.)

THE CORRELATION BETWEEN TILLERING AND PRODUCTIVENESS IN SWEET CORN CROSSES[1]

D. F. JONES, W. R. SINGLETON, AND L. C. CURTIS[2]

THE results obtained by removing the tillers from corn plants has been recently reviewed by Dungan[3] to show that in nearly every case the loss of tillers results in a reduction of yield in both field corn and sweet corn. This investigator has also added the further significant proof that the tillers nourish the main stalk when all the leaves are removed from the main stalk but are left on the side branches.

Nearly all varieties of sweet corn tiller more or less abundantly and especially the earlier sorts. The eight-rowed type of flint corn that is so well adapted to a short cool season also has these side branches. In these types of corn selection of suckerless strains has been attempted but has nearly always failed to establish a desirable variety free from tillering.

From all this evidence we might conclude that tillers serve some useful purpose in the development of the corn plant if it were not for the repeated assertions of many corn growers and agronomists that these so-called "suckers" are of no value and take something away from the main stalk that should go into the formation of ears. They even practice and advocate the removal of these parasites! We might disregard the opinion of practical corn growers when we remember the definition of a "practical man as one who continues to practice the errors of his forefathers," but can we so easily disregard the opinion of agronomists who have been trained in the methods of science, that is, to seek for facts without regard to logical appearances or preconceived theories?

The variety of sweet corn commonly grown in Connecticut for market purposes is Whipple's Yellow. It originated in Connecticut and is characterized by the production of large ears ripening early. No other varieties in this section will produce such large ears in as short a time. The plants are medium in height. The ears are set low on the stalks and there are from one to three or more tillers on nearly every plant. These side branches vary in size from a few inches to the height of the main stalk. Under favorable growing conditions the larger of these tillers produce ears, but these are seldom marketable.

The tillers were removed from this variety by cutting as soon as they were well started, when the main stalk was about 2 feet high. Compared with the untreated plants in alternating rows there was a reduction of 18.9% in total weight of dry ears, 8.2% in number of ears, and 11.6% in average weight of individual ears in a 1-year test. The odds are 10,000:1 that these results are significant. This is a clear indication that tillers are a decided advantage to this variety of sweet corn.

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[1]Contribution from the Department of Genetics, Connecticut Agricultural Experiment Station, New Haven, Conn. Received for publication December 10, 1934.

[2]Geneticist, assistant Geneticist, and assistant in Genetics, respectively.

[3]DUNGAN, GEORGE H., An indication that corn tillers may nourish the main stalk under some conditions. Jour. Amer. Soc. Agron., 23 : 662–670. 1931.

We have recently completed a comparison of a number of first generation crosses of inbred strains obtained from the Whipple variety by self-fertilization for four or more generations. These combinations were made by selecting 6 of the best inbreds out of about 100, basing the selection on stalk growth, production of ears, and ear type. These six inbreds were crossed on each other and on all of the other inbreds after discarding the weakest. These crosses were tested 3 years. After the first trial the poorer crosses were dropped out and new combinations were made between inbreds that appeared to be promising. From 56 to 295 different combinations were grown over a period of 3 years in which a record was made of the number of tillers per plant and compared with the total weight of ears, the weight of marketable ears, and the number of marketable ears. At the time the selection of the inbreds and their various combinations was made no consideration was given to the presence or absence of tillers. Many inbred strains make few or no tillers, although crosses from them were well tillered due to the increase in vegetative vigor.

In making the correlations shown in Table 1, the average number of tillers per plant was used. This is obviously not the best measure of the effect of tillering since the total leaf area is probably a more important consideration. Plants with three or four small tillers might not have as much leaf area as other plants with one large tiller. The various crosses were grown in equal sized plats in fields that were fairly uniform in fertility. There was some variation in the number of plants per row and this undoubtedly had a variable effect on the number of tillers. To guard against an undue influence from this environmental factor, the correlations were made between the average number of tillers per plant and the weight and number of ears per plat. A failure to secure a perfect stand would tend to increase the number of tillers per plant but would not increase the number or weight of ears per plat. On the other hand, these figures would be reduced somewhat. The correlations obtained are therefore probably lower than the actual correlations.

Any positive correlation due to an environmental effect on tillering and on yield would be a further indication of the value of tillers, but this obscures the inherited tendency that was specifically studied. Yield records are based on mature, air-dry ears with the husks removed.

It will be noted in Table 1 that there is a positive and significant correlation between the number of tillers and the total weight of ears in 1929 and 1931. None of the correlations for 1930 is significant. There is a significant positive correlation between the number of tillers and the weight of marketable ears in 1929. No figures are available for 1931. There is no significant correlation with the number of marketable ears in any year.

The positive correlations are additional proof that tillers not only are not detrimental, but, on the other hand, are distinctly useful in this type of early maturing sweet corn.

In 1931, correlations were calculated separately for the crosses with one inbred strain in common. The results are shown in Table 2. Clearly some inbreds have the ability to make their tillers more useful

TABLE 1.—*Correlation between average number of tillers per plant and production in crosses of inbred strains of Whipple's Yellow sweet corn.*

	1929	1930	1931
Total weight of ears per plat	+.20±.04	+.11±.09	+.31±.06
Weight of marketable ears per plat	+.17±.04	+.18±.09	———
No. of marketable ears per plat	+.10±.04	+.02±.09	—.01±.06

to their hybrid offspring than do others. Furthermore, those inbreds that show a high correlation in the crosses derived from them also impart high yielding ability, as shown in Table 3. Strains 474–39, 474–82, and 474–76 gave the highest yields when crossed. They are not only notable in yield but also in number, size, and attractiveness of the ears. Of these strains, 474–82 and 474–76 failed to show significant correlations between tillering and yield. This seems to be due to the fact that all of the crosses were uniform in tillering and yielding ability. The standard deviations for tillering and weight of ears are low for the series of crosses in which 474–82 and 474–76 were used as one parent.

TABLE 2.—*Correlation between the number of tillers and the number and weight of ears in a series of first generation hybrids of Whipple's Yellow sweet corn, each having one inbred in common.*

Inbred parent	Number of marketable ears and number of tillers	Weight of ears and number of tillers
474–2	+.35±.09	+.73±.09
474–39	+.32±.09	+.38±.09
474–55	—.21±.11	—.04±.14
474–76	+.29±.09	+.38±.13
474–82	+.02±.01	+.06±.02

TABLE 3.—*The effect of one inbred parent on the number of tillers and the number and weight of marketable ears in a series of first generation crosses of Whipple's Yellow sweet corn.*

Inbred parent	Tillers, No. per plat	Ears, No. per plat	Weight of ears, lbs. per plat
474–82	38.3±1.0	28.5±.6	8.2±.1
482–5	37.3±1.0	30.8±.8	7.8±.2
474–39	34.8±1.1	28.2±.4	8.7±.1
474–2	27.6±1.2	27.8±.5	7.9±.1
482–2	26.7±3.3	25.1±.4	7.8±.2
474–55	23.7±1.1	26.2±.6	7.2±.2
474–76	21.0± .9	29.7±.6	8.2±.1

The crosses with 474–76 average the lowest in number of tillers and yet are second both in number of ears and in weight of ears. This seems to be an exception to the rule that tillering is advantageous, but it should be remembered that the number of tillers is not the important consideration. It is the leaf area on the tillers that aids production. Here we may have a case where the plants produce a few

large tillers. No record was made of this point. It was noted that the crosses with 474–76 were not as early in ripening as most of the other crosses.

If a corn plant has a long growing season, it can produce enough foliage on the main stalk to ripen a large ear, but in short-season varieties the plant can make a larger amount of foliage in the same time by tillering than it can without this aid to increased production.

All of the evidence at hand bears out the contention that tillers are beneficial to the corn plant and are particularly important for market garden types of sweet corn where early production of large ears is a prime consideration.

FIFTEEN YEARS OF SELECTION IN SIX VARIETIES OF BARLEY[1]

MERRITT N. POPE[2]

INTERNODE length of spike is a quantitative character showing considerable variation in a pure line, not only from year to year but also in the populations grown from a single spike and even in the spikes from a single plant. It would seem that such a variable character, which is easily measured, would be particularly favorable for testing the validity of the pure-line theory. Fifteen years ago Hayes and Harlan[3] had finished their density studies on barley, and, as their material was available, this experiment was begun to see whether the spike internode length of these barleys could be altered by selection.

METHODS AND MATERIALS

The following varieties were available from the work of Hayes and Harlan: Svanhals, two-rowed, dense, white, hulled; Hanna, two-rowed, lax, white, hulled; Jet, two-rowed, medium dense, black, hull-less; Deficiens, deficient, lax, white, hulled; and Manchuria, six-rowed, medium dense, white, hulled. In addition, a head selection of Hannchen, which is a two-rowed, medium dense, white, hulled sort, was added to the list. Of the varieties used, only Svanhals is known to be of hybrid origin. It was developed at Svalöf, Sweden, from a cross of a common two-rowed sort (probably a Chevalier) and Imperial, which is dense and two-rowed. From this hybrid came the variable variety Diamond. Further selection in Diamond produced the quite different varieties Svanhals and Primus. As Svanhals was first imported into this country in 1901, the original cross must have been made a number of years previous to that time. This variety has shown a marked tendency in certain years toward a branching spike with attendant irregularities in internode length. All the remaining varieties are from single spikes of pedigreed sorts in the origin of which no hybridization is known to have played a part.

Individual spikes from the 1917 plantings were selected showing extreme variations from the mean of the 1916 parental populations on the basis of data obtained in the density studies of Hayes and Harlan. From the progenies of these spikes in 1918 spikes were taken which showed extreme variation in the same directions as those of the parent spikes. No density seedings were made in 1919, but the selections from the 1918 crop, together with the pure line Hannchen, were sown in 1920 under irrigation at Aberdeen, Idaho, where the material has since been grown. Seeds from a single spike were spaced in the row and a single representative spike was harvested from each plant for density measurement.

Beginning with 1922, two spikes each of five families selected for long inter-

[1]These studies were made in connection with cereal experiments conducted cooperatively at Aberdeen, Idaho, by the Idaho Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication December 18, 1934.

[2]Agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. The writer wishes to express his appreciation to Miss Lucille Reinbach, Junior Statistician, Division of Cereal Crops and Diseases, for aid in determining and checking some 1,800 means, and to C. G. Colcord, Scientific Aid, Division of Cereal Crops and Diseases, for computing the regressions.

[3]HAYES, H. K., and HARLAN, H. V. The inheritance of the length of internode in the rachis of the barley spike. U. S. D. A. Bul. 869. 1920.

node length and of five families showing short internode length were grown each year in head rows. Densities were determined upon each spike in the head-row population and the extreme variations in the desired direction preserved. The means were then figured and the head row from each pair of "sib" spikes showing less extreme measurements was discarded. From the remaining row the two spikes the measurements of which were most extreme were chosen for sowing the following year. In this way two selections were effected each year, one within the family represented by two head rows and the other within the spike population of the head row selected from the previous year's crop. Thus opportunity was given for cumulative effect of selection toward greater density in five families and toward less density in five families in each of the six varieties.

So far as practicable, all density measurements on the spikes were made on the 10 internodes between nodes 7 and 17. This distance was shown by Hayes and Harlan to have less variability than that in any other part of the spike. Determinations were made in the beginning by direct comparison with a celluloid or steel metric measuring rule, but later the distance was obtained with sharp-pointed dividers and the spread measured in millimeters upon a steel rule.

The experiment was concluded with the 1932 crop for all varieties except Hanna. The measured difference between lax and dense populations was greater in that year than it had been in that variety heretofore. Then, too, many of the spikes had showed, beginning in the 1925 crop, a tendency (evidently a mutation) toward opposite nodes. This made accurate density measurements difficult. For these reasons Hanna was again grown in 1933, when, instead of harvesting but one spike per plant, all were taken. In measuring, all abnormal spikes were discarded, and from the remainder a random sample was taken to represent the plant.

No precautions were taken to prevent cross pollination, since the amount of natural crossing in barley is very low.[4] The varieties used are so distinct that hybrids are easily recognized. Five such hybrid spikes were noted in the density rows during the whole period, four occurring in Jet and one in Svanhals. It is thought that the possible effects of cross pollination are negligible.

In order to determine whether there is a consistent trend over the period, the regressions of the differences between internode length of lax and dense selections were calculated yearly. The values of "t" were then computed and the values of "P" obtained from Fisher's table of "t".[5]

EXPERIMENTAL RESULTS

For each year in each variety the mean internode lengths were found for the 10 strains of lax and for the 10 strains of dense selections. The variation in these lengths from year to year is much greater in all varieties, excluding Deficiens, than in any year between lax and dense selections of the same variety. In Deficiens, Hayes and Harlan noted an evident mutation in density appearing in 1918 and shown graphically in the bar graph in Fig. 1.

[4]STEVENSON, F. J. Natural crossing in barley. Jour. Amer. Soc. Agron., 20 : 1193–1196. 1928.

ROBERTSON, D. W., and DEMING, G. W. Natural crossing in barley at Fort Collins, Colorado. Jour. Amer. Soc. Agron., 23 : 402–406. 1931.

[5]FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4., 1932. (Table IV, page 151.)

Particularly noticeable are the minus differences which occur in the data of all varieties excepting Deficiens. For example, the second largest difference between the means of lax and dense selections occurred in Svanhals in 1925. This had a minus value and amounted to 4.3% of the average of the 20 strains studied. In other words, the five families of Svanhals selected for eight generations for long internodes actually possessed shorter internodes than did the five families selected for short internodes. In Hanna a minus difference occurs in 6 out of the 16 years of selection.

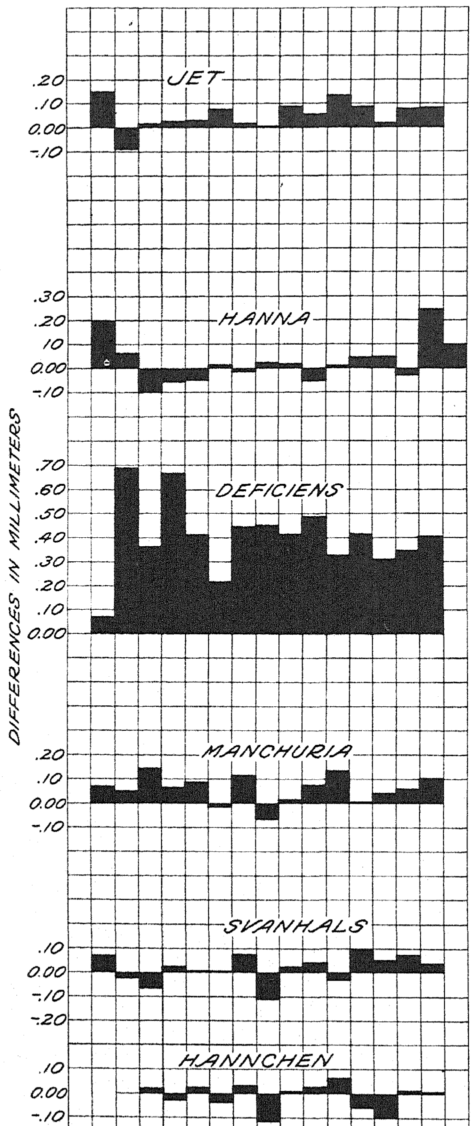

FIG. 1.—Yearly differences in spike internode length between means of lax and dense strains of six varieties of barley.

In Table 1 is shown for each variety, the selection period, the regression coefficient, and its "P" value. "P" values of 0.05 and less are considered statistically significant and are the basis for stating that the amount of variation which gave rise to them could be expected to occur not more than five times in a hundred due to chance alone; consequently, the variation that did occur is attributed to some inherent property of the material under discussion. In no case does "P" have a significant value.

In order to determine whether selection had been effective in any one strain of a variety, the internode lengths of the densest and laxest strains in the last year grown were taken and the an-

TABLE 1.—*The values of "P" found in comparing the means of spike internode lengths in lax and dense selections of each of six varieties of barley.*

	Jet	Hanna	Deficiens	Manchuria	Svanhals	Hannchen
Number of years selected	15	16	15	15	15	13
Coefficient of regression	.0045±.0031	.0045±.0044	.0067±.0099	.0007±.0032	.0037±.0029	—.0011±.0036
Value of "P"	0.171	0.323	0.509	0.826	0.221	0.760

TABLE 2.—*The values of "P" found in comparing the spike internode lengths in the strains found most lax and most dense the last year grown in each of six varieties of barley.*

	Jet	Hanna	Deficiens	Manchuria	Svanhals	Hannchen
Number of years selected	14	16	15	15	15	13
Coefficient of regression	.0117±.0072	.0206±.0072	.0256±.0113	.0119±.0081	.0224±.0047	.0003±.0054
Value of "P"	0.134	0.012	0.042	0.171	0.0001	0.953
Number of years selected	—	last 11	last 13	—	last 11	—
Coefficient of regression	—	.0131±.0133	.0053±.0108	—	.0140±.0065	—
Value of "P"	—	0.351	0.635	—	0.061	—

cestry of each traced back to the original population. The values of the differences between these ancestral internode lengths are plotted on the bar graph in Fig. 2. As before, regressions were calculated and value of "P" found. As will be seen (Table 2), the three varieties Jet, Manchuria, and Hannchen show no significant trend. Hanna, for the total period, does show a significant value for "P". However, when the years 1916 to 1921 are excluded, the variation in the differences in the latter portion of the period indicates no effect of selection.

As has been noted, a mutation for density appeared in Deficiens in 1918. Consequently, there is a significant value for "P" for the whole period, the complexion of which changes completely when the years 1916 to 1917 are omitted.

The remaining variety, Svanhals, has an extremely low "P" value, the trend toward a progressively increasing difference between the laxest and densest strains being evident in the bar graph (Fig. 2). However, the data for the last 11 years of the period bring this variety also out of the significant class.

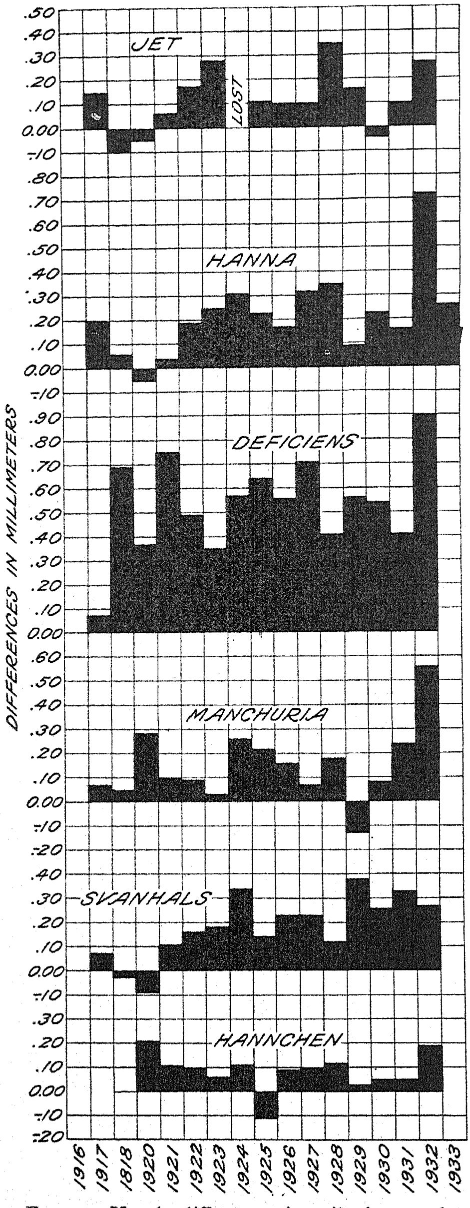

FIG. 2.—Yearly differences in spike internode length in six varieties of barley between the strains found most lax and most dense in the last year grown.

DISCUSSION

In no one of the six varieties used was there a significant trend between the means of the lax selections as compared with the means

of the dense selections. Only when a method was used by which mutations are more easily detected are significant differences found. This method consists of selecting in each variety the strains most divergent for internode length in the last year grown and comparing the ancestral measurements of each year (Fig. 2).

In Jet, Manchuria, and Hannchen neither questions of impurity nor irregularity of behavior during the period have militated against the assumption that they are pure lines. Here the "P" values of the differences both between the means and between the strains found to be most lax and most dense in the last year grown are not statistically significant. In other words, selection has not been effective in producing permanent change in internode length.

In the variety Hanna, the "P" value of the differences between the means of lax and dense strains is 0.323, which is not significant. When the two strains which showed the greatest differences in 1933 were compared, the "P" value is 0.012, which is significant, but, since the "t" test for the last 11 years gives a "P" value altogether too high (seven times) to be significant, there is a strong suspicion that a small mutation for internode length appeared in 1922. Fig. 2 illustrates the lack of trend beginning with this date.

In Deficiens, the differences have been consistently plus throughout the period in both methods of treatment. The mutation for density appearing in 1918 is graphically shown in Figs. 1 and 2. At this point the variety became two pure lines each of which has for 13 years bred true for density, subject only to seasonal variations.

Johannsen[6] defines a pure line as "the descendants from one single homozygotic organism exclusively propagating by self fertilization." This condition can be attained in a plant of heterozygous factorial composition only as a result of self-fertilization continued until all heterozygosity has been eliminated. From the standpoint of practical plant breeding this condition is met in a very few generations of self-fertilization. However, there is always the possibility of the presence of a heterozygous gene in some individual of any later generation. We can never, then, be sure that a variety is a pure line, however long it has been self-fertilized, if it was originally of hybrid origin. Since in Svanhals there is a significantly increasing divergence between its laxest and densest strains (Fig. 2), it is suspected that, due to its hybrid origin, the spike used as the foundation of this line was itself heterozygous for density. Furthermore, its strains have not always acted normally in other particulars, notably in the tendency toward branching and irregular internode length. These facts invalidate the evidence that selection alone was effective in this variety. Since the "P" value for the last 12 years is not significant, it is suggested that purification of this heterozygous condition for internode length occurred in 1921 in one of the two strains compared.

[6]JOHANNSEN, W. The genotype conception of heredity. Amer. Nat., 45 : 135. 1911.

SUMMARY AND CONCLUSIONS

No change in spike internode length of barley is evident in any of six varieties after 15 years of selection when the mean of the lax strains and the mean of the dense strains are compared.

When the strains most divergent for spike internode length in the last year grown are compared, three varieties, Jet, Manchuria, and Hannchen, show no significant trend.

A suspected mutation in density appeared in 1922 in Hanna. No significant trend is evident in 11 years of selection following that date.

A density mutation appeared in 1918 in Deficiens and was effective in producing a permanent difference in internode length.

A "progeny drift (genorhep)" has been recognized only in the case of Svanhals, a barley of hybrid origin.

In a total of approximately 35,000 plants studied there have occurred one mutation for internode length in Deficiens, one for irregularly spaced nodes in Hanna, and a suspected one for internode length in Hanna.

INHERITANCE OF RYE CROSSABILITY IN WHEAT HYBRIDS[1]

J. W. TAYLOR AND K. S. QUISENBERRY[2]

THE possibility of obtaining desirable economic varieties of plants from hybridizing distantly related species or genera continues to be of considerable interest. The results so far obtained have been discouraging, as incompatibility or sterility is found to exist at one or more of the vital phases necessary to begin or continue the work. This is especially true in hybridizing wheat and rye. Here, owing to the almost total sterility of the F_1 plants, very large F_1 generations are necessary. Unless wheats are used that will cross rather easily with rye, it is difficult to obtain a large F_1 generation. The problem may become still further complicated by the fact that the wheat varieties that cross readily with rye do not carry the desired agronomic characters. Any procedure that will further the success of transferring desirable rye characters, especially winterhardiness, to wheat is of considerable value.

REVIEW OF LITERATURE

Wheat varieties differ decidedly in their crossability with rye, as shown by Firbas (2)[3] and Jesenko (3). Firbas obtained no conclusive results on the value of different environmental factors in crossing wheat with rye. No extensive testing of the common American wheats for rye crossability has been made, but so far as known no economic variety is outstanding for this character. Certain Chinese wheats, however, cross readily with rye as shown by Backhouse (1), Thompson (7), and Leighty and Sando (4). The almost total sterility of the F_1 wheat-rye hybrid has been shown by Jesenko (3) and Leighty and Taylor (5).

METHOD AND MATERIALS

The purpose of these experiments was to develop a method whereby large numbers of desired F_1 wheat-rye combinations could be obtained to facilitate breeding for more winterhardy wheats. This was attempted by two methods, as follows:

1. By crossing a variety (Purplestraw) of low crossability with rye (Abruzzes); backcrossing the resulting F_1 with Purplestraw, allowing this wheat-rye wheat type to self, and testing the resultant individuals for inherited crossability.

2. By crossing winterhardy varieties (Minhardi and Minhardi x Minturki, C. I. 8034) of low crossability with a rye crossable wheat (Chinese) (4), which, however, is not winterhardy, and obtaining crossable hardy types of wheat.

The experiments were conducted in the greenhouses and in the field at the Arlington Experiment Farm near Washington, D. C.

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[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication December 19, 1934.
[2]Associate Agronomist and Agronomist, respectively.
[3]Figures in parenthesis refer to "Literature Cited," p. 153.

EXPERIMENTAL DATA

TRANSFERRING CROSSABILITY TO WHEAT TYPES BY HYBRIDIZING WHEAT AND RYE

The data in Table 1 show that Purplestraw was low for crossability with rye, as a seed set of only 1.5% was obtained. Five varieties of rye were used in pollinating Purplestraw, but no individuality in crossing was shown by the ryes. When the F_1 of Purplestraw x rye was backcrossed with wheat, there resulted two seeds in some 1,000 pollinations. These two seeds produced plants that dehisced normally and were self-fertile. The progeny of one of these plants, designated in Table 1 as wheat-rye-wheat, consisted of 10 individuals, all of which were pollinated with rye. Eight of the 10 plants showed crossability, and from pollinating the 10 plants a 19% seed set was obtained. Further pollinating of the wheat-rye-wheat line with rye showed crossability of over 30%.

TABLE 1.—*Rye crossability of certain wheat varieties and hybrids.*

Variety or hybrid	C. I. No.	No. of flowers pollinated	No. of seed set	Seed set %
Purplestraw	1915	1,497	23	1.5
Minhardi	5149	84	1	1.2
Minhardi x Minturki	8034	42	0	0
Chinese	6223	548	378	69.0
(Minhardi-Minturki) x Chinese (F_1)	—	238	3	1.3
Minhardi x Chinese (F_1)	—	218	0	0
Wheat-rye-wheat (F_2)	—	448	85	19.0
Wheat-rye-wheat (F_3)	—	835	276	33.1
Wheat-rye-wheat (F_4)	—	48	17	35.4

The wheat-rye-wheat type is in all morphological appearances true wheat resembling closely the Purplestraw parent. However, in addition to its crossability with rye, one additional character of genetic importance was manifested. Of the 20 F_1 hybrids of wheat-rye-wheat X Abruzzes rye that matured, two dehisced some of their anthers and one gave a single selfed seed. From this seed originated a so-called nonsegregating line intermediate between wheat and rye. So far as is known, no certain instance of natural anther dehiscence or of self-fertility in an F_1 wheat-rye hybrid has been reported. Love and Craig (6) obtained one seed under open-pollinated conditions, which, they believe, may have been a selfed seed.

INHERITANCE OF CROSSABILITY IN WHEAT HYBRIDS

The winterhardy varieties Minhardi and Minhardi-Minturki, C. I. 8034, showed low crossability with Dakold rye (Table 1). The tender Chinese variety, however, under similar conditions gave a 69% seed set when pollinated with Dakold. The F_1 hybrids of Minhardi X Chinese showed no seed set and (Minhardi-Minturki) X Chinese, only a 1.3% seed set when crossed with rye.

As may be seen from the data in Table 2, segregation for crossability occurred in the F_2 generation. Eighty-one individual plants of the Minhardi X Chinese cross were pollinated with rye, 48 gave no seed, 19 gave less than 10% with an average set of 3.8, and 14 gave a seed set of 10% or more with an average of 27.3. In Table 2 these are listed in arbitrary classes of crossability as none, light, and heavy.

TABLE 2.—*Rye (Dakold) crossability of F_2 plants of Minhardi X Chinese and (Minhardi-Minturki, C. I. 8034) X Chinese grouped into arbitrary classes of crossability.*

No. of plants tested	Arbitrary class for crossability	No. of flowers pollinated	No. of seeds set	Crossability with rye %
		Minhardi X Chinese		
48	None	1,880	0	0
19	Light	878	33	3.8
14	Heavy	550	150	27.3
Total 81	—	—	—	—
		(Minhardi-Minturki, C. I. 8034) X Chinese		
59	None	2,040	0	0
17	Light	628	27	4.3
12	Heavy	481	165	34.3
Total 88	—	—	—	—

The F_2 of Minhardi-Minturki X Chinese was very similar to the preceding cross as may be seen from Table 2. In this case of 88 individuals, 59 plants set no seed, 17 showed a light set, with an average of 4.3%, and 12 gave a set of 10% or over with an average of 34.3%.

Inasmuch as crossability behaved as a recessive character, and to hold to the purpose of the experiment, only those F_2 plants showing crossability and vigor were continued in the F_3. The results of testing individuals in the F_3 generation are given in Table 3. Eight F_3 lines of Minhardi X Chinese, involving 47 plants, and 10 lines of (Minhardi-Minturki, C. I. 8034) X Chinese, involving 84 individuals, were crossed with rye. The lowest crossability in any F_3 line was approximately 12% and the highest over 80%. Where the crossability was as low as 12%, several pollinations gave no seed, but this is attributed to pollinating conditions rather than lack of crossability.

WINTERHARDINESS OF F_4 LINES CROSSABLE WITH RYE

A preliminary field test for winterhardiness of F_4 lines of Minhardi X Chinese and (Minhardi-Minturki) X Chinese showing rye crossability was made in the nursery during the crop year 1933–34. On two dates in February the mercury dropped to —7° F. As may be seen in Table 4, the Chinese parent had a very poor survival, whereas Minhardi and Minhardi-Minturki, C. I. 8034, had good and excellent survivals, respectively. The F_4 lines ranged from very poor to excellent in survival. Some lines apparently were equal to the winterhardy parent in this test and nearly all were better than the Chinese

parent. From this preliminary test of winterhardiness it is indicated that a combination of the two characters, i. e., crossability with rye and winterhardiness, has been obtained.

TABLE 3.—*Rye (Dakold) crossability of F_3 lines of Minhardi X Chinese and (Minhardi-Minturki, C. I. 8034)X Chinese.*

Line number	No. of plants	No. of flowers pollinated	No. of seeds set	Crossability with rye, %
		Minhardi X Chinese		
51	6	117	34	29.1
52	8	137	55	40.1
53	9	167	74	44.3
54	10	190	22	11.6
55	7	124	27	21.8
66	3	26	13	50.0
67	2	38	9	23.7
69	2	29	25	86.2
		(Minhardi-Minturki, C. I. 8034) X Chinese		
56	10	186	45	24.2
57	8	147	18	12.2
58	10	201	114	56.7
59	10	186	84	45.2
60	9	176	59	33.5
61	8	154	39	25.3
62	9	168	51	30.4
63	10	197	77	39.1
64	8	159	57	35.8
65	2	33	27	81.8

TABLE 4.—*Comparative winter survival of F_4 rye crossable lines of Minhardi X Chinese, (Minhardi-Minturki) X Chinese, and parent.*

Variety or hybrid	Number of F_4 lines or parents surviving				
	Very poor	Poor	Fair	Good	Excellent
Minhardi X Chinese	2	10	16	10	2
(Minhardi-Minturki, C. I. 8034) X Chinese	4	14	16	26	1
Minhardi	—	—	—	1	—
Minhardi-Minturki, C. I. 8034	—	—	—	—	1
Chinese	1	—	—	—	—

DISCUSSION

Crossability of wheat with rye is a heritable character that can be transferred to wheat segregates by hybridizing wheat and rye. By this method a strain similar to wheat was produced, which, in addition to its crossability with rye, gave two F_1 hybrids showing some anther dehiscence and one of which produced a selfed seed. Pollen development to the extent of causing natural dehiscence of anthers and self-fertility, under controlled conditions, has never before been observed. However, it is possible that the slight fertility reported by Love and

Craig (6) in their F_1 wheat-rye hybrid may have been true self-fertility and not the result of backcrossing with wheat.

Transferring the rye crossability present in known varieties of wheat to more desirable wheat segregates by intervarietal crossing was readily accomplished. The results confirm the preliminary report of Backhouse (1), who pollinated 17 F_2 plants of a crossable X non-crossable wheat and found four that set seed. Although in both cases the numbers are small, crossability appears to be controlled by a main recessive genetic factor. It is possible, however, that minor modifying factors may also be present.

LITERATURE CITED

1. Backhouse, W. O. Note on inheritance of "crossability". Jour. Gen., 6 : 91–94. 1916.
2. Firbas, H. Über die Erzeugung von Weizen-Roggen Bastardierungen. Ztschr. Pflanzenzücht., 7 : 249–282. 1920.
3. Jesenko, E. Über Getreide-Speziesbastarde (Weizen-Roggen). Ztschr. Induktive Abstam. u. Vererbungslehre, 10 : 311–326. 1913.
4. Leighty, C. E., and Sando, W. J. Natural and artificial hybrids of a Chinese wheat and rye. Jour. Her., 19 : 23–27. 1928.
5. ———, and Taylor, J. W. "Hairy neck" wheat segregates from wheat-rye hybrids. Jour. Agr. Res., 28 : 567–576. 1928.
6. Love, H. H., and Craig, W. T. Fertile wheat-rye hybrids. Jour. Her., 10 : 195–207. 1919.
7. Thompson, W. P. Chromosome behavior in a cross between wheat and rye. Genectics, 11 : 317–332. 1926.

POLE BEANS VS. SOYBEANS AS A COMPANION CROP WITH CORN FOR SILAGE[1]

R. G. WIGGANS[2]

WITH the increased interest, particularly in the northeastern United States, in the combination of a legume with corn for silage purposes has come the question, many times repeated, "Why not grow pole beans with corn for silage?" This question was postulated on the assumption that production would be equally good and some of the difficulties of harvest would be eliminated due to the ability of the pole bean to use the corn plant as a support and to remain with the corn plant at harvest time without loss of a significant amount of the legume.

The purpose of this brief report is to present data obtained from experiments planned to give information on this problem.

METHOD

In 1933, a pole bean, Kentucky Wonder, was included in the regular experiment where soybean varieties were being tested with corn for silage. The test was twice repeated in 1934, one series only receiving inoculation.

In order to be able to compare the yield of the combinations with corn alone, a given variety of corn was grown at a uniform rate over a considerable area with soybeans or pole beans planted with the corn in three out of four rows. The fourth row served as a check and also gave a measure of the ability of the land to produce corn alone. The rate of corn planting was the optimum for corn silage under the conditions of the experiment, namely, 9 inches apart in rows 3 feet apart. Soybeans or pole beans when added were planted at the rate sufficient to give three legume plants to one of corn. Almost a perfect stand of corn was obtained by accurate spacing at planting time and dropping two or three kernels where one plant was desired, followed by subsequent thinning. The legumes were not thinned but a stand approaching closely to that desired was secured by planting an excess of 10% germinable seed over the amount necessary for the desired stand provided all germinable seed produced plants. The individual rows were 50 feet long and were repeated eight times. Two standard silage corn varieties for the region were used. In order to show the contrast between pole beans and soybeans, two varieties only of soybeans were taken from the several in the test.

The corns and the legumes were harvested separately and weighed immediately. Shrinkage samples were taken on three of the eight series (approximately 40 pounds of corn and the entire harvest of soybeans) and later kiln dried in order to determine the dry matter percentage in the green material and finally by taking the average of the three shrinkage samples to get the dry weight production of the corn and of the legume separately. The percentage dry shelled grain in the corn was also determined in the shrinkage samples.

RESULTS

The fact that a legume grown with corn for whatever purpose reduces the yield of corn, whether measured in total dry matter pro-

[1]Paper No. 207, Department of Plant Breeding, Cornell University, Ithaca, New York. Received for publication December 20, 1934.
[2]Professor of Plant Breeding.

duction or yield of grain, has long been established and needs no further proof. The total production of dry matter, however, is a controversial point and needs further evidence. The data given in Tables 1 and 2 are presented as evidence on this problem. Kentucky Wonder pole beans when grown with West Branch corn caused an average loss in dry weight production of the corn of 2,363 pounds per acre, or 28%. When grown with Cornell No. 11 corn, the loss was 2,107 pounds per acre, or 27.3%. Corresponding losses in grain production were 753 pounds, or 33.5%, in West Branch and 992 pounds, or 33.0%, in Cornell No. 11. The losses in dry weight production were not made up by the yield of the bean which on the average was 745 pounds of dry matter when grown with West Branch and 752 pounds with Cornell No. 11. The differences between the losses of corn and the production of the legume showed an average loss of 1,618 pounds, or 19.8%, in total dry matter when Kentucky Wonder pole beans and West Branch corn were grown together, while a similar loss of 1,351 pounds, or 18.7%, occurred when Cornell No. 11 was used. These differences are large, consistent, and statistically significant, giving satisfactory proof of the inadvisability of growing the two together for silage purposes under conditions similar to those of the experiment.

The duplicate series of plats as grown in 1934 showed no statistical difference as a result of inoculation. This was due to the fact that the plants of both series showed approximately equal inoculation, thus giving satisfactory proof of the presence in the soil of the proper organism for bean inoculation. The final results of the 1933 test had aroused the suspicion that the pole beans had not been inoculated and that the small yield of the legume and the depressing effect on the corn might be explained on that basis. No observations were made on the amount of inoculation in 1933. It had been assumed that the proper organism for inoculation was present, an assumption proved to be correct by the 1934 results.

In order to show the effect of soybeans on corn and the total dry matter production, data similar to that given for Kentucky Wonder pole beans is given for Wilson and Peking soybean varieties, the one to represent the indeterminate and the other the determinate habit of growth. (Any two of several other varieties might have been chosen with similar results.) Here, again, decreases in the total dry matter in West Branch corn were 12.4% and 14.5%, while grain showed decreases of 18.9% and 20.0%. The soybean varieties gave yields of dry matter equivalent to 17.8% and 20.3% of corn alone. The losses in total dry matter production in corn were more than made up by the yields of the soybeans. Actual increases of 5.3% and 6.8% occurred in total dry matter production. Cornell No. 11 corn when grown with the same varieties of soybeans showed corresponding increases of 9.2% and 7.2%.

The contrasting behaviors of pole beans and soybeans, when grown with corn for silage, resulted in approximately twice as much decrease in the corn yield with pole beans as with soybeans and a production of approximately half as much dry matter. This caused an average loss of 19% in total dry matter in one case and a 7% gain

TABLE 1.—*West Branch corn in combination with pole beans and soybeans for silage.*

Legume	Variation from theoretical check in dry weight*						Gain or loss of combination compared with corn alone	
	Total corn		Corn grain		Legume			
	Lbs. per acre	Per-centage	Lbs. per acre	Per-centage	Lbs. per acre	Per-centage	Lbs. per acre	Per-centage
				1933				
Ky. Wonder pole bean	—2,009	—23.3	—481	—23.7	395	4.6	—1,614±181	—18.7
Wilson soybean	— 899	—10.6	—209	—10.5	1,413	16.7	514±111	6.1
Peking soybean	— 843	—10.3	—206	—10.5	1,562	19.1	719± 64	8.8
				1934				
Ky. Wonder pole bean†	—2,617	—33.8	—906	—44.3	927	12.0	—1,690± 77	—21.8
Ky. Wonder pole bean	—2,462	—31.8	—871	—42.6	912	11.8	—1,550± 99	—20.0
Wilson soybean	—1,112	—14.3	—560	—27.4	1,468	18.9	356±151	4.6
Peking soybean	—1,295	—16.7	—605	—29.6	1,664	21.5	369± 67	4.8
				Average 1933–34				
Ky. Wonder pole bean	—2,363	—28.0	—753	—33.5	745	8.2	—1,618± 96	—19.8
Wilson soybean	—1,005	—12.4	—384	—18.9	1,440	17.8	435± 94	5.3
Peking soybean	—1,069	—14.5	—405	—20.0	1,613	20.3	544± 46	6.8

*Probable errors were calculated for all variations from theoretical checks, but are not included because in no case was the P.E. equivalent to 10% of the difference.
†Inoculated.

TABLE 2.—*Cornell No. 11 corn in combination with pole beans and soybeans for silage.*

Legume	Variation from theoretical check in dry weight*						Gain or loss of combination compared with corn alone	
	Total corn		Corn grain		Legume			
	Lbs. per acre	Per-centage	Lbs. per acre	Per-centage	Lbs. per acre	Per-centage	Lbs. per acre	Per-centage
1933								
Ky. Wonder pole bean	—2,233	—26.3	—1,211	—34.4	302	3.6	—1,921±196	—22.6
Wilson soybean	—1,342	—15.9	— 884	—25.2	1,613	19.1	272±133	3.2
Peking soybean	—1,449	—17.3	— 920	—26.5	1,653	19.7	204±127	2.4
1934								
Ky. Wonder pole bean†	—1,890	—26.3	— 826	—29.7	957	13.3	— 936±220	—13.0
Ky. Wonder pole bean	—2,197	—30.6	— 940	—33.8	1,001	13.9	—1,196±183	—16.6
Wilson soybean	— 718	—10.0	— 394	—14.2	1,809	25.2	1,091± 94	15.2
Peking soybean	— 945	—13.1	— 477	—17.1	1,807	25.1	862±117	12.0
Average 1933–34								
Ky. Wonder pole bean	—2,107	—27.3	— 992	—33.0	752	8.6	—1,351±121	—18.7
Wilson soybean	—1,030	—12.9	— 639	—19.7	1,711	22.1	681± 81	9.2
Peking soybean	—1,197	—15.2	— 698	—21.8	1,730	22.4	533± 86	7.2

*Probable errors were calculated for all variations from theoretical checks, but are not included because in no case was the P.E. equivalent to 10% of the difference.

in the other. These extreme differences may be explained at least partially by:

1. The more vigorous growth of pole beans at early stages with an increased shading effect and greater demand for nitrogen and other food nutrients. It was observed that the corn seedlings growing with Kentucky Wonder beans started slower in the spring. This handicap was never overcome.

2. The fact that the Kentucky Wonder pole bean produces a greater shading effect throughout the period of elongation as a result of its twining habit and larger leaves.

3. The fact that twining prevents to a greater or less extent the full expansion of all corn leaves.

4. The pole bean was for the most part mature at harvest time. This condition was partly the result of the early pods remaining on the plants and thus causing physiological maturity at an earlier date than if the pods had been removed, while the soybeans were in an active state of growth throughout the season.

Table 3 is given to show the actual yields of corn when grown alone. By the use of this table with the two preceding ones, the average yield of the combinations may be calculated.

TABLE 3.—*Yield of corn grown alone.*

Year	Corn variety	Dry weight per acre, lbs.	
		Total	Grain
1933	West Branch........	8,415±128	1,986±30
	Cornell No. 11.......	8,448±123	3,506±51
1934	West Branch........	7,752± 76	2,046±20
	Cornell No. 11.......	7,191±100	2,783±39

Although only 2 years' results are available, the extreme differences between the behavior of pole beans and soybeans when grown in combination with corn and the very significant loss in total dry matter when Kentucky Wonder pole beans are used with corn for silage seem to justify the following conclusions for conditions similar to those of New York state:

1. That Kentucky Wonder pole beans cannot be grown to advantage with corn for silage.

2. That the loss in dry weight production of corn in a corn and soybean combination is more than made up by the dry weight production of the soybeans.

NOTE

EFFECT OF OVER-GRAZING ON KENTUCKY BLUEGRASS UNDER CONDITIONS OF EXTREME DROUTH

IN a survey taken in October 1934 by H. D. Hughes, H. L. Eichling, and F. S. Wilkins of Iowa State College in the severe drouth area of southwestern Iowa, it was found that about 90% of the Kentucky bluegrass was killed by the combination of drouth and heat during the summer of 1934. The rainfall was only about 50% of normal during June, July, and August and temperatures were over 100° for 30 days or more during the summer. In most of the pastures of this section 90 to 95% of the Kentucky bluegrass, which comprised nearly all of the cover, was found to be dead. Scattered, small, weakened, live Kentucky bluegrass plants, however, remained.

Throughout the survey, which was made about 3 weeks after fall rains began, it was observed that the pastures which had been the most closely grazed suffered the worst, and three pastures within 2 miles of each other near Clarinda, showing remarkable contrast in condition, gave mute evidence of the disastrous effect of over-grazing. In the most heavily grazed pasture spindly bluegrass plants, 1 to 3 feet apart, were being kept eaten off at ground level by many hogs. Over 99% of the Kentucky bluegrass in this pasture was dead and practically no live cover remained. Across the fence about 75% of the bluegrass had been killed and vegetation consisting of Kentucky bluegrass and foxtail was being given considerable opportunity to develop. This pasture gave the appearance of having been moderately to heavily grazed during the drouth period and before.

Within 2 miles a pasture was found on the same soil type and of similar topography where the turf and cover of Kentucky bluegrass were excellent, with practically no dead plants. The operator stated that this pasture had been grazed moderately to lightly in 1933 and 1934 while he had charge of the farm. He said also that during the drouth period of 1934 the top growth gave every appearance of being dead.

Evidence that over-grazing aggravated effects of drouth and heat and was the indirect cause of the death of about 90 per cent of the Kentucky bluegrass was so convincing that there is little doubt that discontinued or intermittent grazing will be the most effective means of restoring such pastures. Reseeding with legumes, and in some cases grasses as well, and soil treatments will be helpful, but each farm operator even of limited means can give his pasture needed rest by providing small grain and other emergency pastures. The Iowa workers would like to have the ideas of other agronomists concerning this important problem.—F. S. WILKINS, *Iowa State College*, *Ames*, *Iowa*.

AGRONOMIC AFFAIRS

NEWS ITEMS

DR. D. F. JONES, head of the Department of Genetics of the Connecticut Agricultural Experiment Station at New Haven and recently elected President of the Genetics Society of America, delivered the Spragg Lectures at Michigan State College. His topics were as follows: "Genes, Present and Missing;" "The Interpretation of Hybrid Vigor;" "The Production of Inbred Strains of Corn;" and "The Testing and Utilization of Inbred Strains of Corn."

A CORRESPONDENT of the U. S. S. R. reports increasing interest in iarovization in the Soviet Union. It is reported that almost universal application of the process is being made to wheat, sugar beets, potatoes, oats, barley, millet, sunflower, lupins, cotton, grasses, and legumes.

NUMBER 10 of the periodical published by the All-Union Institute of Plant Industry of the U. S. S. R., known as "Socialist Plant Industry," contains the following articles: "Soviet Scientific Plant Industry During the Period of Socialist Reconstruction," by N. I. Vavilov; "Soviet Cytology and Plant Industry for the Past Year," G. A. Levitsky; "The Study of Hybridization of Plants," by G. D. Karpachenko; "Soviet Agro-physiology and Its Achievements During Recent Years," by T. A. Krasnosellskaya-Maximova; and others. Number 9 of this periodical contains a complete bibliography of all books and bulletins which appeared in the U. S. S. R. during 1932 on the subject of plant industry. While the periodical is published in Russian, most of the titles have English translations.

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PASTURE AREAS IN THE UNITED STATES[1]

H. N. VINALL[2]

IN the United States there are five fairly definite pasture regions resulting from climatic conditions. Due to the response of various pasture plants to either temperature or rainfall conditions, or both, each region may be appropriately divided into two sections, a northern and a southern.

CHARACTERISTICS OF DIFFERENT PASTURE REGIONS

Since temperatures, rainfall, topography, and soil each have a marked effect on the distribution and character of the flora, these features of the pasture regions outlined above are discussed briefly. Most attention, however, is given to the vegetation which characterizes each region.

TEMPERATURES

Anyone who has given the least consideration to vegetation characteristics knows that climate is the chief factor governing the distribution of plant species over the earth. In the United States, the 60° isotherm marks as closely as any temperature factor available the northern limit of usefulness of southern pasture plants such as the bermuda, carpet, Dallis, and centipede grasses. The exceptions to this general rule are mostly annuals such as the hopclovers, lespedeza, and Sudan grass. North of this line southern perennials are not fully winterhardy and are on the whole less valuable than the northern type of pasture plants. South of this isotherm bluegrass, orchard grass, timothy, redtop, and the clovers, which are at home and provide productive pastures in Region 1 and Sec. 5a, do not thrive because of the long period of high temperatures.

The discussion of the temperature factor relates chiefly to the humid regions (1, 2, and 5a) because in the Great Plains and Intermountain area (Regions 3 and 4) rainfall exerts a greater influence on the vegetation than do temperatures. The line of demarcation between the floristic groups is of course not sharp. The southern type

[1]Contribution from Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Presented as part of a symposium on "The Relation of Pastures to the Land Utilization Program," at the annual meeting of the Society held in Washington, D. C., November 22, 1935. Received for publication December 10, 1934.

[2]Senior Agronomist.

is found north of isotherm 60° and the northern type south of it. In other words, there is on any of these arbitrary division boundaries an overlapping of the characteristic flora of the adjoining divisions. This is in many cases due to soil differences. On the whole, however, a large proportion of the pasturage in a given region is supplied by the type of vegetation indicated on the map (Fig. 1).

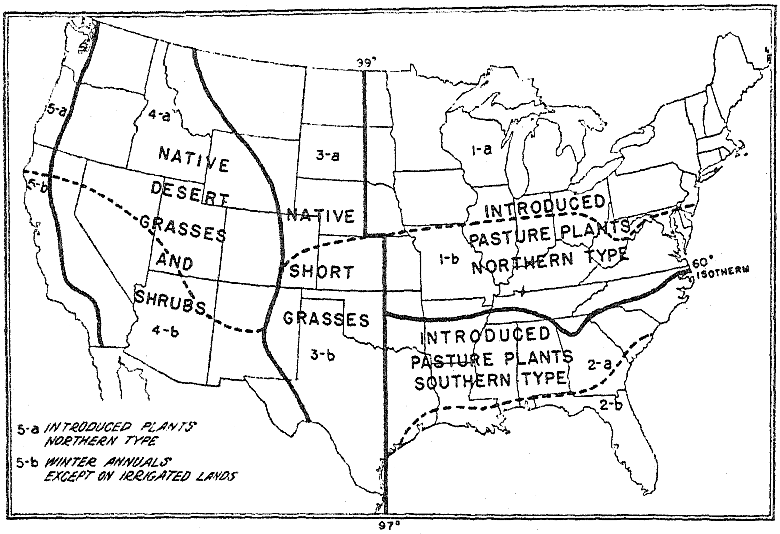


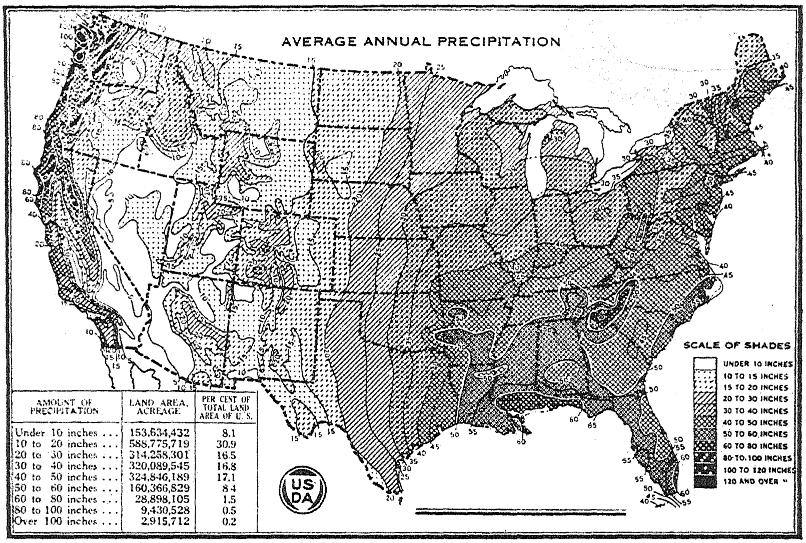
FIG. 1.—The five natural pasture regions as determined by climate are indicated by solid lines. Each of these regions is subdivided by dotted lines into sections *a* and *b*, chiefly because of their temperature relations, except on the Pacific slope where *a* represents the more or less humid northern section and *b* the rather arid southern section. The kinds of pasture plants which provide most of the pasturage in each region are indicated. (From U. S. Dept. of Agriculture, Misc. Pub. No. 194. 1934.)

PRECIPITATION

The available soil moisture as affected by precipitation in the form of rain and snow becomes the controlling factor in respect to the flora west of Regions 1 and 2 (Fig. 2). The western boundary of these regions is a combination of the 99th meridian in the North and the 97th meridian in the South. In proceeding west through the eastern humid area this line marks the approximate western limit where introduced pasture plants are more productive for grazing purposes than native plants. The line separating Regions 1 and 2 from Region 3 veers to the west as it approaches our northern boundary because the total evaporation from a free water surface during the warm seasons, April to September, inclusive, is about 30 inches at the Canadian boundary and over 65 inches at the Mexican boundary line. The effectiveness of the annual rainfall varies with the relation of the rainfall to the evaporation. Thus 20 inches of rainfall in North Dakota will produce crop yields equivalent to a 30 inch rainfall in Texas.[3]

[3]KINCER, J. B. Atlas of American Agriculture. Part II, Sec. A: 48.

This relation of rainfall and evaporation in its effect on crop yields was pointed out first by Briggs and Belz in 1910.[4] Some authorities have attempted to follow soil lines in marking the eastern boundary of the Great Plains, but so far as crop production is concerned rainfall is the limiting factor and is believed to be the most important one in separating the pasture regions.



AMOUNT OF PRECIPITATION	LAND AREA, ACREAGE	PER CENT OF TOTAL LAND AREA OF U. S.
Under 10 inches ...	153,634,432	8.1
10 to 20 inches ...	588,775,719	30.9
20 to 30 inches ...	314,258,301	16.5
30 to 40 inches ...	320,089,545	16.8
40 to 50 inches ...	324,846,189	17.1
50 to 60 inches ...	160,366,829	8.4
60 to 80 inches ...	28,898,105	1.5
80 to 100 inches ...	9,430,528	0.5
Over 100 inches ...	2,915,712	0.2

FIG. 2.—Lines of equal annual precipitation or isohyets in the United States. (From U. S. Dept. of Agriculture Yearbook, 1921: 418.)

In Region 4 the annual precipitation is so low that desert or semi-desert conditions prevail over all this region except in the extreme northern part and at high altitudes in the mountains.

The northern half of Region 5 (Sec. 5a) has a fairly abundant winter rainfall and a mild climate due to the Japan Current. This climatic condition results in dense coniferous forests, mostly spruce, and in very productive improved pastures.

TOPOGRAPHY

The contour of the United States is broken by three important mountain ranges extending in a general north and south direction from the Canadian boundary line nearly to the southern boundary of the United States. The easternmost is the Appalachian system, the central and highest is the Rocky Mountains and the one near the Pacific Coast is composed of the Sierra Nevada and Cascade ranges. West of the latter ranges, however, are a series of low groups of mountains quite near the ocean which as a whole are referred to as the Coast Range.

[4]BRIGGS, L. H., and BELZ. J. O. Dry farming in relation to rainfall and evaporation. U. S. Dept. Agr. Bur. Plant Ind. Bul. 188: 21. 1910.

The mountain areas, because they are rather completely forested and composed mostly of rock masses with very little productive soil, are unimportant from a pasture standpoint. In some of the mountain valleys at high altitudes it is possible to establish good improved pastures and in the West cattle and sheep are often moved into the foothills from the low-altitude ranges when the pasturage on the latter proves inadequate.

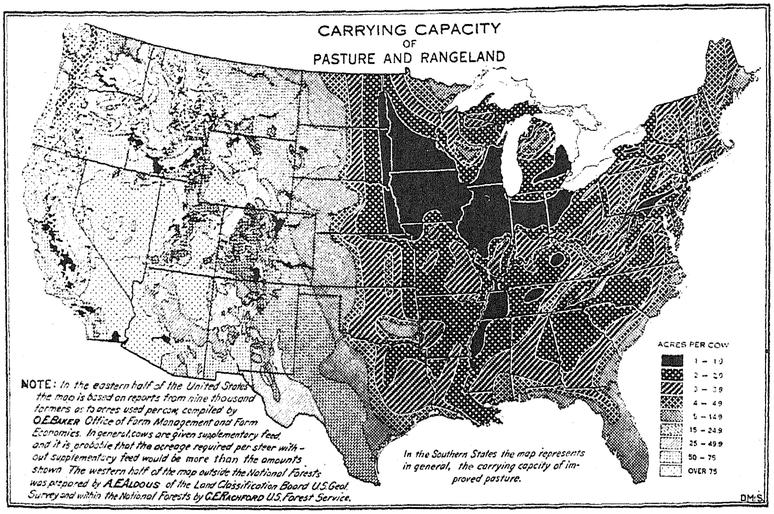


FIG. 3.—The estimated carrying capacity of pastures and range lands in the United States. In general the areas having the largest percentages of tame pastures have the highest carrying capacity. (From U. S. Dept. of Agriculture Yearbook, 1923: 383.)

The most valuable grazing lands are the level or rolling lands in humid sections like the corn belt. When such areas have a productive soil it requires less than 2 acres to support one animal unit during the grazing season. The level lands in the Great Plains are also good pasture lands, but are less productive than similar grazing lands in the corn belt because of low rainfall. The low, swampy lands bordering the Atlantic and Pacific oceans and the Gulf of Mexico are occupied generally by tall, coarse grasses and by sedges and rushes. Such vegetation is lacking in both palatability and nutritive value, hence its carrying capacity is low. A map of the United States showing the estimated carrying capacity of pastures and range-lands shows clearly where the most productive pastures are found (Fig. 3).

SOIL RELATIONS

Next to climate and topography soil characteristics have the most influence not only on the productiveness, but also on the type of pasture plants which occupy the land. The carrying capacity of pastures indicated in Fig. 3 is, in areas having similar climatic condi-

tions, highest on the notably rich soils of the corn belt. The presence of legumes in pastures also increases their nutritive value and legumes are with few exceptions most abundant on soils of limestone origin. In considering the vegetation found in the various pasture areas, at least the broader phases of soil characteristics should be kept in mind. The main soil groups or provinces of the United States are shown in Fig. 4.

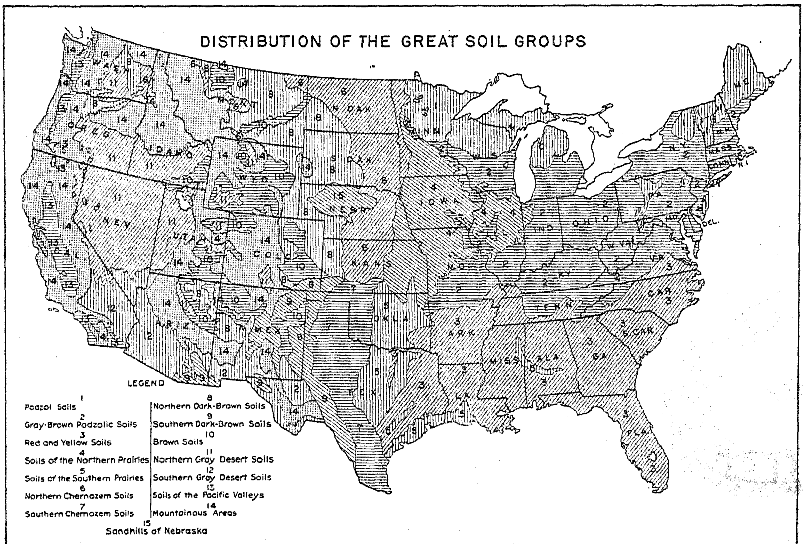


FIG. 4.—This map, prepared by Dr. C. F. Marbut, indicates only the major soil differences. In each of these Regions there are areas of varying size which differ in certain essentials. The detailed soil survey maps issued by the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, and by the states show these minor variations.

Leaving out of consideration the mountain areas, the land surface of the United States is divided into seven large soil provinces. In the order of their productiveness, if the influence of climate is ignored, the prairie soils would rank first; the chernozem or black soils, second; the dark-brown soils, third; the gray desert soils, fourth; the gray-brown podzolic soils, fifth; the podzols, sixth; and the red and yellow soils, seventh or lowest in inherent productivity because they are leached more than any other group of soils. The small soil group known as the soils of the Pacific valleys are deep sedimentary soils which are naturally productive, perhaps equalling in this respect the second or third groups indicated above. If only pasture Regions 1 and 2 where the rainfall is normally adequate are considered, the four soil provinces would rank in productiveness as follows: (1) Prairie, (2) gray-brown podzolic, (3) podzols, and (4) red and yellow.

The high ranking of the desert soils may seem unjustified, but their inherent productiveness is demonstrated whenever they are irrigated. Lack of adequate rainfall in the Great Plains also reduces the actual

production of the dark-brown and black or chernozem soils which intrinsically are very little less productive than the Prairie soils.

The effect of the depth of the soil has a considerable influence on the kind of grass and other forms of vegetation which occupy the land. The tall prairie grasses do not succeed where the rainfall is inadequate or the soil structure is such that the roots cannot penetrate to a considerable depth.

VEGETATION

The vegetation most important from a pasture standpoint is the grasses and legumes. In Regions 1, 2, and 5 these are preponderantly introduced species, but even in such cases it is desirable to know what class of native vegetation preceded the introduction of foreign plants.

Region 1.—Almost all of this region was originally hardwood forest and the land had to be cleared of trees before it could be cultivated and seeded to pasture plants. The chief exception to this rule was the tall-grass prairie extending eastward from eastern North and South Dakota, Nebraska, and Kansas through southwest Minnesota, Iowa, and northern Missouri into central Illinois. Big bluestem (*Andropogon furcatus*)[5] generally associated with Indian grass (*Sorghastrum nutans*) was the dominating species on these prairie lands and small areas of this splendid hay and pasture grass are still found, although such reminders of the early days are rare because the prairie soils were productive and more easily prepared than timber lands for growing cultivated crops. In the drier habitats, particularly on the western edge or transition zone of the prairies, the little or bunch bluestem (*A. scoparius*) predominates and often penetrates into the plains or short-grass formation. This dominance of the little over the big bluestem and its penetration into the short-grass formations is especially noticeable in the eastern parts of Nebraska, Kansas, and Oklahoma. Farther north in western Minnesota and the eastern edges of North and South Dakota the prairie formation is largely a combination of needlegrass (*Stipa spartea*) and slender wheatgrass (*Agropyron tenerum*).

Considering Region 1 as a whole, Kentucky bluegrass is by far the most important pasture grass. In mixture with white clover it is nearly always present on productive soils in permanent pastures. Next in importance are Canada bluegrass, redtop and its allies the bent grasses, timothy, orchard grass, brome grass, and the fescues. South of the dotted line in Section 1b, lespedezas, Korean and common, are becoming increasingly abundant in pastures and greatly increase their carrying capacity, especially during the summer months.

In the eastern part of Section 1a the permanent pastures on poor upland soils and where they are neglected and overgrazed are occupied chiefly by sweet vernal grass and poverty grass along with such weeds as ox-eye daisies, goldenrod, dandelion, yarrow, wild carrot, cinquefoil, hawkweed or devil's paintbrush, hardhack, briars, yellow devil, and brakes or ferns.

[5]The technical names are given for native pasture plants and shrubs because of the confusion existing in their common names.

The poorly drained wet meadows in Section 1a are usually occupied by bluejoint (*Calamagrostis canadensis*), marshgrass (*Spartina pectinacea*), Reed canary grass (*Phalaris arundinacea*), sedges, and rushes. Seaside bent is also found on many wet areas along the New England coast.

Southward in the eastern part of Section 1b poor pastures are characterized by the invasion of broom sedge, poverty grass, foxtail, crabgrass, and such weeds as chicory, buckhorn, bracted plantain, yarrow, sorrel, whitetop, and thistles.

In the western part of Sections 1a and 1b poor or neglected pastures are invaded by foxtail (*Aristida oligantha*), quackgrass, and such weeds as yarrow, ironweed, sorrel, buckhorn, knotweed, whitetop, shepherd's purse, and thistles.

Region 2.—This also was originally a forested region, but unlike Region 1 the predominating type of forest in the southeast was coniferous, composed of longleaf, loblolly, and slash pines on the Coastal Plain, and an oak-pine association at the higher altitudes. The native herbaceous vegetation following the lumbering operations in these forests is varied, but has a low nutritive value for the most part except in the spring. Grasses predominate and many of them, particularly the *Andropogon* and *Aristida* spp., are known locally as "wire grasses".

In Section 2a, which lies almost wholly in the cotton belt, the native grasses of most importance on cut-over land are *Andropogon scoparius*, *A. tener*, *Aristida purpurascens*, *Sporobolus gracilis*, *Panicum angustifolium*, *Gymnopogon ambiguus*, and *Andropogon elliottii*. Broom sedge (*Andropogon virginicus*) is abundant on land which has been cleared and abandoned for crops. The legumes found with these grasses in rather limited numbers are from the standpoint of abundance *Stylosanthes biflora*, *Galacta erecta*, *Lespede-a repens*, *Meibomia arenicola*, *M. marylandica*, and *Cracca ambigua*.

The improved pastures in Section 2a are almost wholly introduced grasses and legumes. Carpet grass on moist sandy soils and bermuda grass and lespedeza on loam, clay, and silt soils supply a large percentage of the pasturage in this section. Dallis grass and Johnson grass also contribute a great deal of pasturage, while the centipede, Rhodes, vasey, and rescue grasses have only a limited value because they are local in their distribution. Among the legumes in improved pastures lespedeza is by far the most important. The hop and bur clovers are widely distributed and white clover and black medic are important on soils which have a fair calcium content. Cluster and Persian clovers are later introductions which may find a place in southern pastures.

Section 2b is the subtropical belt along the Gulf of Mexico. Here, as in Section 2a, the native woods grasses in the "flatwoods" and on cut-over land supply considerable grazing. Those most important are *Andropogon hirtiflorus*, *Sporobolus gracilis*, *Muhlenbergia expansa*, *Aristida condensata*, *Andropogon elliottii*, *A. virginicus*, and *A. tenarius*. The principal legumes found in association with these grasses are *Galactia floridana*, *Bradburya virginiana*, *Meibomia triflora*, *Cracca chrysophylla*, *Galactia volubilis*, *Crotalaria rotundifolia*, and

Chamaecrista fasciculata. There are many other grasses and legumes found by Reed[6] in his pasture surveys, *Aristida virgata* and *A. stricta* being perhaps the most valuable of these.

The improved pastures in Section 2b like those of Section 2a are largely carpet, bermuda, and centipede grasses, but in addition we find others such as bahia, para, guinea, molasses, St. Lucie, and natal grasses which are all confined to practically frost-free localities and are not, therefore, suited to Section 2a. The Natal grass, although abundant in the Florida peninsula is of little value for grazing because it is unpalatable. Pastures in Section 2b are notably deficient in legumes.

Along the Atlantic Coast from New Jersey southward the brackish marshes of the Coastal Plain are characterized by several species of *Spartina* (*Spartina alternifolia* and *S. patens*) and by sedges and rushes. In the swampy or wet lands of the interior in Sections 1b and 2a are found not only several species of sedges and rushes, but the tall reed-like grasses, small cane (*Arundinaria tecta*) near the Atlantic Coast and large cane (*A. gigantea*) of the lower Mississippi Valley. The latter formed the original cane brakes of our southern states. The reed (*Phragmites communis*) is distributed widely along water courses throughout the eastern states. All of these wetland grasses supply some pasture, but the reeds and canes of the fresh-water marshes are superior in palatability and nutritive value to those growing on the sandy and brackish soils near the coast. In the Everglades of southern Florida, saw grass (*Cladium jamaicense*) predominates; it is of little value for grazing purposes. Farther west in Section 2b near the Gulf Coast there is an abundance of pifinne (*Panicum hemitomum*) and some species of *Spartina* with sedges and rushes. The pifinne is not only grazed at certain times of the year, but is also cut, dried artificially, and ground for feed.

Region 3.—In Region 3, as previously indicated, a large proportion of the pasturage is supplied by the native short grasses. Forests as such are almost unknown in this region which is predominantly level upland with a gradually increasing altitude from the eastern border to the 5,000-foot contour line on the eastern side of the Rocky Mountains. Some trees are found bordering the streams on the chernozem or black soils of the eastern edge of this region. It is this black soil belt also that is really the transition zone between the prairies and the plains vegetation. Into this zone the bluestems penetrate quite freely, especially along the water courses and drainage channels which are ordinarily dry. At the bottom of such channels or low places the vegetation may be largely big bluestem, while on the rough banks or brakes little bluestem predominates. Along the actual water courses big bluestem occupies the bottomland and little bluestem in association with big bluestem the second bottoms, while the higher rougher land is an almost pure stand of little bluestem until the level upland is reached where the short grass begins.

[6]REED, H. R. Unpublished reports on botanical studies of reforestation plots at the Coastal Plain Experiment Station, McNeill, Miss., and pasture plots at the Chinsegut Hill Sanctuary, Brooksville, Fla., and the Penney Farms, Fla.

West of the chernozem soils in the zone of dark-brown and brown soils is found the true short-grass formation due mostly to the low rainfall but to some extent to the soil. Shallow-rooted plants thrive best on this soil because the carbonate layer is comparatively close to the surface and the subsoil is permanently dry. In the North the principal grasses are an association of blue grama (*Bouteloua gracillis*) and western needle grass (*Stipa comata*) with a small admixture of June grass (*Koeleria cristata*). The most characteristic weeds in this association are pasture sage (*Artemisia frigida*), silvery psorale (*Psoralea argophylla*), and the coneflower (*Echinacea angustifolia.*) On the heavier gumbo soils are both large and small areas of the western wheat grass (*Agropyron smithii*) useful both for pasture and as hay. This formation is confined mostly to North and South Dakota and the northwestern part of Nebraska. In northeastern Wyoming and eastern Montana, the vegetation is largely blue grama, but includes also nigger-wool (*Carex filifolia*) and June grass. Near the mountains the formation is often interrupted by sagebrush areas. In this northern part grasses are more readily established on abandoned crop land than in the southern part. Crested wheat grass. brome grass, and slender wheat grass may be grown successfully on such lands.

The middle section of the Great Plains in western Nebraska, Kansas, Oklahoma, and northwestern Texas has a very typical short-grass association of buffalo grass (*Bulbilis dactyloides*) and blue grama. In many places there are great expanses of an almost pure stand of these two grasses. Often, however, there is mixed in this basic formation taller grasses like western wheat grass, western needle grass, side-oat grama (*Atheropogon curtipendula*), and the three-awn grass (*Aristida longiseta*). Psoralea (*Psoralea tenuifolia*), prickly pear (*Opuntia lindheimeri*), and in wet years, horseweed (*Erigeron canadense*) and gum-weed (*Grindelia squarrosa*), are the most characteristic weeds.

Farther south below the Texas Panhandle the black grama (*Bouteloua eripoda*) and the curly mesquite (*Hilaria belangerii*) take the place of the buffalo grass and blue grama as the most important pasture plants. Here the turf becomes progressively more open as we near the Rio Grande River and the mesquite trees, soap-weed (*Yucca elata*), bear grass (*Yucca glauca*), and sacahuista (*Nolina erumpens*), as well as other desert plants, become more abundant. A narrow belt along the river is in reality an extension of the desert, Section 4b. All of the short-grass region supplies excellent pasturage, although the carrying capacity is much lower than that of tame pastures in humid regions.

The most important breaks in this short-grass vegetation are the sandhill section of Nebraska and the sandy soils of northwestern Oklahoma known as the "shinnery" lands. On these sandy soils we have mostly tall grasses rather than buffalograss and gramagrass. In the Nebraska sandhills the *Calamovilfa longifolia*, *Stipa* sp., *Sporobolus cryptandrus*, *Panicum virgatum*, *Andropogon scoparius*, *A. hallii*, *Bouteloua hirsuta*, *Muhlenbergia pungens*, and *Psoralea lanceolata*, along with the sandhill plum (*Prunus angustifolia watsonii*), are the most characteristic. In the "shinnery" we find bunchgrass, mostly

Andropogon species, associated with the shin oak (*Quercus havardii*). This oak is rarely over 3 feet in height and represents a transition to the southern desert shrub.[7]

In Regions 3 and 4, Section 5b and the drier parts of Section 5a, wherever irrigation is not practiced, the most effective method of improving the natural pastures is by proper protection of the native vegetation. This means a system of grazing which will not destroy the better, more palatable species. Such grazing systems, adapted to different parts of the arid intermountain area, have been developed by the Forest Service in the national forests and by the state and federal experiment stations in the Great Plains. Controlled grazing is absolutely essential to the protection of these lands from erosion and to their continued productiveness. Seeding these arid range lands with tame or introduced pasture plants has resulted for the most part in dismal failures.

Region 4.—The production per acre of pasturage in this region is the lowest of any of the five regions because the annual rainfall varies from 10 to 15 inches over most of it and in the central and southern parts is usually less than 10 inches. Only in the favored section around Moscow, Idaho, and Pullman, Wash., in the high mountain meadows, and in irrigated sections can any reasonable growth of tame pasture plants be expected.

In the northern part including western Montana, northern Idaho, northern Oregon, and eastern Washington, especially in the Moscow-Pullman section, thin stands of wheatgrass (*Agropyron spicatum*), little bunchgrass (*Fescue idahoensis*), and Sandberg's bluegrass (*Poa sandbergii*) are found. Where the rainfall is less abundant a bunchgrass condition of these same grasses, wheatgrass and *Poa* along with bunch wheatgrass (*Agropyron scoparius*), appears.

In southern Idaho, Utah, and Nevada the true desert shrub vegetation characterized by the large sagebrush (*Artemisia tridentata*), the shadscale (*Atriplex confertifolia*), and the salt sage (*Atriplex corrugata* and *A. nuttallii*) are encountered. The large sagebrush even extends east of the Rocky Mountains in Wyoming, Colorado, and Montana, as well as north into Oregon and Washington in certain unfavorable situations. During rainy periods the introduced annual brome (*Bromus tectorum*), filaree (*Erodium cicutarium*), and similar herbaceous desert plants spring up and furnish some grazing. Associated with the shadscale is the winterfat (*Eurotia lanata*), one of the most valuable grazing plants in the Great Basin. Sagebrush is found mostly north of latitude 34° except at high altitudes.

In the southern part of this region, including southern Nevada, southern Utah, and California and Arizona, and western New Mexico (Section 4b) at the lower altitudes sagebrush gives way to the creosote bush, the mesquite, and, on alkali soils, the greasewood. The rainfall varies from 2 to 20 inches and most of Section 4b has less than 15 inches, while temperatures often reach a maximum of 125° and rarely

[7]Much of the information regarding Regions 3, 4, and 5 is adapted from Atlas of American Agriculture, Part I, Sec. E, Natural Vegetation, by H. L. Shantz and Raphael Zon, and from U. S. Dept. of Agriculture Misc. Pub. 101, Important Western Browse Plants, by Wm. A. Dayton.

fall below 25° F. Along with the creosote bush (*Covillea tridentata*) goes the desert saltbush (*Atriplex polycarpa*), narrowleaf saltbush (*Atriplex linearis*), mesquite (*Prosopis juliflora*), and chamisa (*Atriplex canescens*). There are also in this southern area a large variety of yuccas and cacti some of which grow to a remarkable size. Here, also, are palo verde (*Cercidium torreyanum*), catsclaw (*Acacia greggii*), lechuguilla (*Agave lechuguilla*), and sotol (*Dasylirion texanum*).

The best grazing areas are in eastern Arizona, western New Mexico, and the extreme western part of Texas. Here the larger part of the rainfall comes during the summer season and a few very drought-resistant grasses are found scattered among the desert shrubs. The most important of these are galletagrass (*Hilaria jamesii*), tobosa grass (*Hilaria mutica*), black grama (*Bouteloua eripoda*), crowfoot grama (*B. rothrockii*), six-weeks grama (*B. aristidoides*), and six-weeks needle grass (*Aristida adscensionis*). Even curly mesquite, one of the valuable grasses in the southern Great Plains, is found in rather thick stands at the higher altitudes in southeastern Arizona. All these grasses are palatable and nutritious.

Region 5.—The rather abundant rainfall in Section 5a, together with the mild climate, makes it possible to establish very high-producing tame pastures of introduced grasses and legumes in this section. Kentucky bluegrass, orchard grass, tall oat grass, timothy, meadow fescue, meadow foxtail, Reed canary grass, the ryegrasses, and the bent grasses thrive here. All of the clovers, but especially ladino, make bountiful pastures. Scarcely any other part of the United States is so well suited to these pasture plants and nowhere else, except on irrigated lands, do pastures have such a high carrying capacity. The most productive pastures are on the bottom lands. On the uplands are vast areas of cut-over lands and comparatively treeless prairie.[8] Here the natural grass cover consists of blue grass, bent grasses, fescues, bromes, velvet grass (*Holcus lanatus*), and white and hop clovers. Such weeds as buckhorn, bracken fern, sorrel, and cat's ear are abundant. Some of these lands have been burned over and seeded to Italian ryegrass, orchard grass, timothy, and red clover. On wet lands which are subject to flooding for short periods, the best pastures consist of seaside bent, meadow foxtail, Italian ryegrass, and alsike clover. On lands which are frequently under water for long periods Reed canary grass or seaside bent may be grown successfully.

The native grasses on the range along the mountains above the cultivated uplands and merging into the forests were originally populated with many of the bunch grasses which are now found east of the Cascade Mountains. Due to overgrazing these perennial bunch grasses have been largely superseded by annual fecues, bromes, wild oats (*Avena* sp.), and bur clover intermingled with deer brush and other woody browse plants.

In the southern part of the Pacific Slope, Section 5b, the rainfall is much less than in Section 5a, but is like it in respect to being very largely a winter rainfall. In the interior valleys, therefore, most of the pastures are irrigated like the fields which grow harvested crops.

[8]McCollam, M. E. Permanent pastures. Wash. Agr. Exp. Sta. Bul. 211. 1927.

Alfalfa is the most productive pasture in these valleys and is grazed more successfully here than in the eastern states due to less trouble with bloat. A pasture mixture found very satisfactory, particularly in the San Joaquin Valley south of San Francisco is a combination of Dallis grass, Italian ryegrass, alfalfa, and ladino clover. Such pastures have a high carrying capacity and can be grazed heavily with less injury than the pure alfalfa.

In the foothills, where desert-like conditions are encountered at the lower altitudes, the grasslands merge into the shrubby chaparral oak (*Ouercus emoryi*) and scattered desert shrubs, mainly mesquite, creosote bush, yuccas, blackbrush, and cat's claw, similar to those on the eastern foothills of the Sierra Nevade Mountains. In the coast range the California chamiso (*Adenostema fasiculatum*), often called "Chamise" covers large areas and is one of the most characteristic chaparral species. In the Mohave Desert the picturesque Joshua tree (*Clistoyucca brevifolia*) is seen in scattered stands with wild buckwheat (*Eriogonum fasciculatum*) covering much of the ground underneath. On the drier slopes encelia (*Encelia farinosa*) forms dense thickets and on more humid slopes this is replaced by the California sage (*Artemisia californica*). None of these desert shrubs are of much value for pasture purposes.

The pasturage on these semi-desert lands consists largely of winter annuals which begin growth with the first rains in late fall and continue through the winter and early spring months. The most common of these are several brome grasses (*Bromus rubens*, *B. hordeaceus*, *B. tectorum*), wild oats (*Avena fatua* and *A. barbata*), squirrel-tail (*Hordeum murinum*), the legume bur clover (*Medicago hispida*), and an herbaceous spreading annual of the Geranium family known locally as filaree (*Erodium cicutarium*). Both the bur clover and filaree are nutritious grazing plants and very much desired on the ranges, but the annual grasses are low in nutritive value and most of them are objectionable because of their long awns. In protected areas two perennial grasses still persist. These are the California *Poa* (*Poa scabrella*) and California needle grass. (*Stipa pulchra*) Mountain rice (*Oryzopsis hymenoides*) is another perennial which is abundant in some localities.

In the numerous alkali areas salt grass (*Distichlis spicata*) is most abundant, but with it are tussock grass (*Sporobolus airoides*), rabbitbrush (*Chrysanthamus graveolens*), and alkali heath (*Frankenia grandiflora*).

The wet lands or marshes in Section 5b are occupied by Indian rice (*Zizania aquatica* and *Z. palustris*), cattail (*Typha latifolia*), and tule (*Scirpus validus*). Where these marsh lands in the Sacramento and San Joaquin valleys have been diked and drained, they provide very fertile farm areas especially for the production of truck crops.

RELATION OF GRASS COVER TO EROSION CONTROL[1]

H. H. Bennett[2]

MUCH has been said and written about the powerful effect of forests, in controlling erosion and increasing absorption of rainfall, but not nearly enough attention has been devoted to the similar and almost equal effect of grass as a stabilizer of land and as an effective means of increasing absorption. The importance of grass as a means of controlling erosion is so great that this paper may appropriately be prefaced with the assertion that where there is a good cover of grass there is no serious problem of erosion. For this reason it seems time for agronomists and all of those who are interested in the continuing welfare of the crop and grazing lands of the nation to think more of ways and means for increasing the use of grass, and those other thick-growing crops that function after the manner of grass, to the end that by this simple procedure more of the water may be retained where it falls, with less of it running rapidly into the streams, and with more of the soil held in sloping fields where it belongs.

The results of careful measurements of the runoff and erosion from representative areas of 12 major soil types throughout the country show on the average that where grass, or a similar dense crop, is grown 5 times more rainwater is absorbed and 65 times less soil is washed away as compared with the losses of soil and water from exactly the same kind of land, occupying the same slope, and receiving the same rainfall, where clean-tilled crops are grown. These measurements have been made from about the average slope of the soil types involved, and they represent annual losses over a period ranging from 2 to 4 years. In one instance, that of the Colby silty clay loam of western Kansas, the average annual loss of soil from an area devoted to a clean-tilled crop (kafir corn) has been 3,300 times greater than on the same type of soil, occupying the same slope and situated at a distance of only a few feet, where the surface was thickly covered with a native growth of bluestem and grama grass; while the loss of water as immediate runoff has been 437 times greater from the clean-tilled area than from the one covered with grass. The losses from some of the other extensive soils have been quite in line with those of western Kansas.

SOIL AND WATER LOSSES

For example, on an 8% slope of the Shelby silt loam in the rolling part of the north Missouri corn belt, the average annual loss of soil over a 3-year period has been at the rate of 60.8 tons per acre, along with a loss of rainwater as immediate runoff amounting to 27.4% of all the precipitation; whereas, from the same degree of slope on the same farm the corresponding losses from Shelby silt loam under timothy grass have been at the rate of 0.32 ton of soil annually and 7.7

[1]Contribution from the Soil Erosion Service, Department of the Interior. Presented as part of a symposium on "The Relation of Pastures to the Land Utilization Program," before the annual meeting of the Society held in Washington, D. C., November 22, 1934. Received for publication December 10, 1934.

[2]Director, Soil Erosion Service.

of the rainfall. Where the ground was kept bare the corresponding annual losses have been at the rate of 112 tons of soil per acre, along with 26% of the rainfall. Inasmuch as the average depth of soil under the virgin prairie condition of the Shelby silt loam of this locality is approximately 7 inches on 8% slopes, only about 20 years would be required to remove the entire surface layer where corn is grown continuously. Where the ground is kept bare only 11 years would be required to remove the surface layer; but under grass 3,890 years would be required to remove the same depth of soil and under alfalfa 5,845 years would be required. In other words, in this region the probability is that soil builds up from beneath about as fast as it is removed from the surface under a good cover of grass or a good cover of alfalfa.

On February 23, 1934, the most astounding losses of soil occurred in the vicinity of Santa Paula, Calif., as the result of a heavy rain. On 17 farms where measurements were made immediately after the rain, it was found that steep slopes used for clean-tilled orchards had suffered acreage losses of soil ranging from 150 to 525 tons. That there were no measurable losses from the same kind of land on the same farms where the surface was covered with native vegetation is probably one of the most outstanding instances that we know of showing the utterly indispensable place that grass and other forms of stabilizing vegetation must be given in any plan having a chance to accomplish anything approximating permanency in our programs of erosion prevention and control.

COMBINATION OF CONTROL METHODS

It is unfortunate that some specialists have taken the position that erosion can be effectively controlled with a single engineering method of attack, namely, terracing. Terracing (the American type of terracing represents a broad embankment adjusted to slope contours) is generally an effective method for reducing erosion on slopes which especially in case of shallow soils with impervious subsoils, do not exceed about 6 to 10% in declivity, depending on the kind of soil, the degree of erosion as the result of past land use, the intensity of rainfall, and the type of agriculture. Supported by strips of grass, lespedeza, Sudan grass, or other adaptable thick-growing crops, terraces can be helpfully employed on somewhat steeper slopes, especially on those where the soil is deep and absorptive. This method for diverting water must also be recognized as a useful practical measure for carrying water from the upper sides of sharp, erosive slopes to safe drainage ways.

RELATION OF GRASS TO LAND DESICCATION

During the summer of 1934 numerous ranchers asserted publicly and privately that during the past 15 to 20 years, following the steady depletion of the grass by overgrazing, more and more springs have gone dry and numerous streams which formerly ran for considerable periods or throughout the year now carry water only for short periods following rains or the melting of snow. These complaints were frequently heard in Utah and southern Idaho. They were in some mea-

sure suggestive of what C. W. Hobley, a man of long experience on the continent of Africa, recently had to say in discussing the effects of overgrazing in East Africa. Mr. Hobley says, "We are thus confronted with the paradoxes that tsetse-fly is a blessing and water a curse. Where there is water, cattle are concentrated; they eat the grass—seeds, roots and all. With increase of cattle the soil is progressively removed and erosion sets in. To-day, two-thirds of Tanganyika are under the tsetse-fly, and in that two-thirds erosion merely follows the slow natural course. There is no doubt that two-thirds of Tanganyika have been preserved by the fly from erosion and ruination at the hands of the native population."[3]

It might be well to quote here part of a letter recently received from K. S. Sandford, Field Director of the Oriental Institute's prehistoric survey in northeastern Africa. Dr. Sandford says, ". . . the boundaries of the Nile are absolute desert, except within a few miles of the coast and in the Sudan. There is reason to suppose that the coastal belt provided grazing for larger flocks in ancient times than it now does (the Oriental Institute can cite you many inscriptions on this point): the coastal belt was the best wine-growing country in Roman times. There is a strong feeling among most of those who have studied the subject that the present state of affairs on the coast is due to (1) destruction during and before the Arab invasion (2) extreme neglect since that event, i. e. for about 400 years (3) perpetual grazing by goats, the most destructive animal in the world, and grazing of even the most sparsely vegetated regions by camels. It was the Arab who introduced the camel in large numbers into the country. To these factors rather than to any change of climate in the coastal belts is attributed the present state of affairs."

"The northern Sudan from Darfur to the Nile is experiencing a serious encroachment of desert from the north: . . . there is similar trouble with the fringes of the Kalahari and in northern Nigeria. In the arid or semi-arid Sudan also there is observable failure of formerly reliable wells. Some believe that these things are due to an arid period of a climatic cycle, which may be long or short. If you consider that since 1898, when settled government was given to the Sudan for the first known time in history, there have been no major losses of people or cattle, that the people and their flocks have increased by very many millions, that they have continued to live in country with 10-15 ins of rain and a tropical sun, and that they have done extensive cultivation, I think you can see that there may be something in common with your problems. If, now, you turn to Africa south of the Sudan, you see over-population, over-grazing, over-cultivation of exceedingly soft soil that washes away with the over-abundant rains (and will blow away, as in the Sudan, when it is dry). The result is appalling and forms perhaps the greatest problem of British administration in Africa. There is no serious suggestion of total failure of rain in this case."

A survey of a representative farm in Trego County, Kansas, where there was both eroded and uneroded land, made by R. H. Davis in 1931, shows that on this 159-acre farm, consisting in its upland por-

[3]Geographical Review, 24: 662. 1934.

tion of Colby silt loam that was broken out of the original plains grass in 1922, the principal erosional losses from 106 acres of cultivated upland were as follows: 29.3% had lost 3 inches of soil, 28.8% had lost 4½ inches of soil, 33.9% had lost 8 inches of soil, and 0.5% had lost 2 feet of soil and subsoil.

All the eroding areas were losing soil at a strongly accelerated rate, as compared with the areas still retaining a cover of plains grass, and all of this eroded land had suffered markedly in productivity. The most severely washed areas had become excessively droughty and had very little value for the regional crops. The exposed subsoil and the slope was essentially identical with subsoil which, at the Hays (Kansas) Experiment Station, produced on an average of 4.8 bushels of wheat as against an average of 25.2 bushels produced on the practically virgin soil in the same field where the slope and the methods of culture were identical. Here the soil loss from the virgin area has been at the rate of 2 tons an acre and from the corresponding subsoil at the rate of 11 tons an acre, with corresponding water losses of 10 and 19%, respectively.

It is interesting to note in this connection that the vegetation on the typical virgin soil of the Trego County area, which completely covered the ground, consisted of 85% of grasses (buffalo, little bluestem, and blue grama) and 15% of weeds; while that on the eroded soil, originally the same, after 2 years of abandonment consisted of no grass, 2% weeds, and 3% old Kafir stubble, with 95% of the surface bare. In other words, there had been a switch from a 100% ground cover of vegetation to a condition of 95% of non-vegetated surface, with not a single plant on the abandoned eroded area that was found in the original cover.

MORE VEGETATIVE METHODS OF CONTROL NEEDED

The evidence is sufficient to convince anyone that vegetation must be brought more and more into our plans for controlling erosion. One of the principal curses of the American type of agriculture is continuous clean cultivation of sloping erosive land. The decreased productivity and ultimate depletion of most of these lands with the continuation of such usage, is not a matter of opinion but a pre-determined physical fact. In other words, if we are to preserve the body of our soils we must, as speedily as possible, change our farm methods on rolling land in a very marked way. We must practice more crop rotations; we must to an increased degree keep the land covered with thick crops at certain seasons of the year; we must bring strip cropping more into use; and numerous areas of steep, highly erosive land must be stabilized with grass, lespedeza, trees, or other soil-holding crops. In many fields these vegetative practices can be introduced and are being introduced in a practical manner and with the full approval of farmers where the farmer has been shown why and where they should be adopted. This can be accomplished in many instances either by demonstration or through the medium of a map showing the precise physical conditions of a farm and the relation of these conditions in the various parts of a farm to their needs. In the program of the

Soil Erosion Service, now being applied to many millions of acres, this is one of the basic procedures.

PLAN OF PROCEDURE

The method of attack employed by the Soil Erosion Service is essentially a coordinated plan of correct land use. This plan involves not only the use of direct methods of retarding erosion (which necessarily calls for retardation of runoff by increasing absorption of the rainfall), but the use of indirect methods, such as the retirement from cultivation of steep, highly erosive areas from which accelerated runoff (resulting from incorrect land usage) descends with destructive effect upon lower-lying cultivated areas. Such retired critically vulnerable lands are being planted with thick soil-holding crops, such as trees, grass, alfalfa, lespedeza, sorghum, and clover.

Part of the cultivated land is being protected with the new system of strip cropping, under which clean-tilled crops, such as cotton, corn, and tobacco (the real producers of erosion), are being grown between parallel bands of grass, lespedeza, sorghum, and other dense crops planted across the slopes, on the level, i. e., along the contours. These latter crops catch rainwater flowing down the slopes, spread it out, and cause the suspended soil to be deposited and most of the water to be absorbed by the ground, thus protecting the crops growing on the plowed strips below. On certain slopes strips of permanent protective cover will be planted according to the French system, using trees, shrubs, and vines. Here is an opportunity to make advantageous use of nut trees, persimmon, honey locust (producing feed for livestock), briar crops, and other plants of economic value. It is hoped that it may be possible on some of the project areas to employ the Ecuadorian system of protecting steep slopes by bordering the downhill sides of rectangular fields with soil-holding hedges.

Field terraces (embankments adjusted to the contours) are being employed where applicable, and in some localities it is planned to scarify certain types of land, especially summer-fallowed ground, with a machine which scoops out 10,000 basin-like holes to the acre, each of which retains about 5 gallons of rain, causing it to sink into the ground where it falls. Machines for this purpose are now being manufactured. Soil-conserving crop rotations are being practiced and cover crops and other control measures are being employed.

Every farm is surveyed in advance of actual work by specialists of the local erosion staff. Soils, slopes, and extent of erosion are plotted on accurate maps. With the aid of this, the farmer, the erosion specialists, and the crops, engineering, and other specialists go over the farmstead, study it in detail and on the ground plan a course of procedure by assigning each acre to a particular use in accordance with its needs, adaptability, and appropriate place in a carefully planned, coordinated land-use program for that particular farm. The work is carried out on a strictly cooperative basis with the farmers. Generally, the latter are enthusiastically supporting every phase of the program. On some of the projects more than 95% of the farmers are going along with the program of the erosion specialists, agreeing to far-reaching reorganization of their fields and farm procedures. For

example, on numerous farms fences are being relocated so as to permit contour cultivation, terracing, strip-cropping, the inauguration of soil-building rotations, and the planting of the more vulnerable slopes to grass, trees, etc. Such hearty cooperation, it is believed, insures the success of the program. By putting through these initial educational watershed projects in a highly impressive manner, it is felt that it will then be possible to extend the work to all areas through the Extension Service, the colleges of agriculture, state experiment stations, and other organizations, with the assistance of erosion specialists when necessary.

FIRST COORDINATED EROSION-CONTROL EFFORT

Here is the first attempt in the history of the country to put through large-scale, comprehensive erosion and flood control projects, such as apply to complete watersheds from the very crest of the ridges down across the slopes to the banks of streams. These are not engineering projects, or forestry projects, or cropping projects, or soils projects, but a combination of all these, operated conjointly with such reorganization of farm procedure as the character of the land indicates as being necessary. This procedure is based on the best information in the possession of scientific agriculturists, agronomist, forester, range specialist, soil specialist, erosion specialist, agricultural engineer, economist, extension specialist, game specialist and, geographer. It is the application of accumulated knowledge pertaining to the great multiplicity of variables affecting the three-phase process of absorption, runoff, and erosion employed not as single uncoordinated implements of attack, but collectively, according to the needs and adaptability of the land, in a combination of integrated control measures, supplemented by new information accruing from the experience of combat.

No such coordinated attack has ever before been made against the evil of erosion in this country. Considering the physical, economic, and social factors involved, it is believed there is no other possible practical method of ever making any effective headway against this vicious problem. Even if the government owned the land, it would still have to be used over large areas in the production of crops and for grazing; and here again precisely the same physical problems would have to be met and conquered, an eventuality that unavoidably precedes all other consideration relating to correct land use.

EXAMPLES OF PROCEDURE

In the Wisconsin erosion project covering Coon Valley near La Crosse, for example, some of the steep timbered areas, now eroding because of excessive grazing, are being taken out of use and given complete protection in order to stop the excessive runoff of rainwater, which has been speeding down across the cultivated slopes, ripping them to pieces with gullies or planing off the more fertile topsoil. Grass is being restored to these protected forest areas, and where the trees are too thin other trees are being planted. Small plantings and seedings are being made that furnish feed and cover for quail and ruffed grouse. Eventually, with increased stocks of these fine game

birds, saved from starvation during prolonged periods of snow, as was done last winter, sportsmen will come from Milwaukee, St. Paul, Chicago, and other places to pay the farmer for the privilege of hunting in his timbered lands.

Below the forested land, the steep slopes now washing rapidly to a condition of low productivity are being taken out of the clean-tilled crops and put into permanent pasture to furnish the grazing that formerly was provided by the timbered areas. The grazing capacity of the farms is not thus increased or materially decreased, but the crop area is cut down to some extent. Better protection of the cultivated land from erosion will largely make up for this reduction by way of higher acreage yields.

On the 150,000-acre watershed erosion project on Big Creek in north-central Missouri, extending into south-central Iowa, a report of progress submitted by the regional director of the soil erosion work, under date of June 23, 1934, includes the following highly pertinent statement with respect to accomplishment, work having begun on this area in the spring of 1934: "At this time we have 401 cooperative agreements signed up with the farmers of the Big Creek project, and over 63,000 acres of land under contract for a coordinated plan of erosion treatment. We have been successful in reducing the corn acreage over the next 5-year period by more than 37 percent on these farms. We have cut the acreage of land where corn follows corn for a second year (a very bad practice) more than 54 percent. We have very materially increased the acreage of pasture. We are planning an intensive program on pasture improvement, beginning this fall and continuing into next spring. While weather conditions have been quite unfavorable, it is felt that very good progress has been made to date."

Thus, all indications point to successful achievement with these coordinated, educational programs of erosion control—which, it should be emphasized in conclusion, are of an experimental-demonstrational nature, and which, by reason of the necessary procedures involved with the accomplishment of a complete job, extend beyond the mere task of controlling erosion.

CONCLUSION

In conclusion, it should be emphasized again that a successful program of erosion control is going to call definitely for battling for more grass, more dense soil-stabilizing crops, and better adjustment of farm procedures to the physical characteristics of the land. The agronomist must hold a key position in this battle. It is hoped that he will distribute his forces so as to push the line of attack to every position needing attention.

ECONOMIC ASPECTS OF PASTURE IN THE LAND PLANNING PROGRAM[1]

C. L. HOLMES[2]

TWO important factors have been responsible for pushing a consideration of pastures to the foreground in land-use planning. The first is the surplus crop production which has characterized our agriculture in recent years and the second is the conservation of soils and other natural resources. The first of these factors began to make itself felt in a tangible way in the depression of 1920 and 1921 and became acute with the present depression, culminating in the Government program to reduce surpluses of the crops in which the problem was most acute, and to adjust the acreage of crops and the number of livestock and the volume of the output of livestock products into a rational relationship with the existing and potential demand. The second of these factors we have had with us for many years, but it has been singularly overlooked in popular attention until the present administration embodied it in its comprehensive program of conservation and adjustment.

These two factors give ample justification for the importance which the pasture question has assumed. The issue, on first consideration, seems reasonably clear. We should shift substantial portions of land from erosive crops to grass, refit the organization of farms to this adjusted use of farm land, and achieve the double objective of reducing the total farm output of crops and livestock to a volume which corresponds to the demand for their use, and at the same time conserve in perpetuity our nature-given agricultural resources.

Unfortunately this solution meets with other forces which involve serious difficulties and make it much more difficult than it appears upon the surface. One of these forces is the pressure of people on farm land, induced by the large amount of unemployment in nonagricultural industries, which has been occasioned by the depression. Not only has there been a stopping of the normal flow of population from agriculture to industry, but there has developed a back flow of people from industry to agriculture which constitutes a resistance to the proposed program, the significance of which seems as yet only partly realized. More people on the land usually means more intensive use, whereas a greater dominance of pasture tends to mean less intensive use. There is the further factor of the individual farmer's interest in the proposal to place a larger proportion of land in pasture, and of his reaction to this proposal. Whatever the program, it must be worked out in the light of these two factors.

Finding the best ultimate place of pastures in the planning for agriculture must be worked out through a program that will reconcile these two sets of opposing forces. Such reconciliation will be extremely

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difficult, but there seems no reason for believing that it cannot be made. In its working out, both agronomists and economists have an important responsibility.

In the following discussion it is proposed, first, to present information on the place which pasture now holds in American farm economy; second, to discuss ways in which the use of pasture is involved in the farmer's problem of the organization and management of his farm; and, third, to present what appears to be the major points relating to pastures in land-use planning.

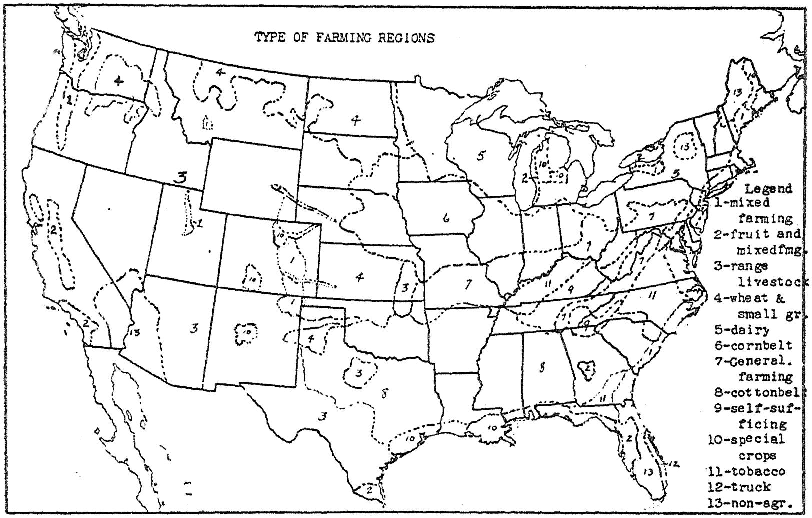

FIG. 1.—Location of regions listed in Figs. 2 and 5.

THE PLACE OF PASTURES IN AMERICAN FARMING

It will help to place our pasture problems before us to consider some data on the present place of pasture in American farming and the trends in its importance, and to compare the place it holds in our farming with its importance in certain foreign countries.

According to the 1930 census, there were in 1929 just a little less than a billion acres of land in American farms. Of this area approximately 89% was in pasture and crop land; the remaining 11% being in woods not pastured, in building sites, and in waste land. Of the land in crops and pasture, 52% was pasture and 48% was in crop land. Of the pasture, only 27% was reported as tillable. The remainder was pastured woodland and other untillable land used as pasture.

Fig. 1 shows 12 regions as blocked out for purposes of analysis by the Planning Division of the Agricultural Adjustment Administration. Fig. 2 shows the percentage of all farm land in pasture by these regions. An examination of Fig. 2 shows important variation in the relative importance of pasture. These variations, running from about 20% in truck farming to about 80% in the range livestock region, reflect the relative advantage of pasture and its uses under the differ-

ent physical and economic conditions that characterize the different regions.

It will be interesting at this point to compare the position of pasture in this country with its position in certain groups of foreign countries. Recalling the figures of 48% in crops and 52% in pasture as shown by the 1929 census for our own country, let us consider first a group of countries characterized by a very high percentage of farm land in pasture. In the Irish Free State, for example, crops occupy only 33%

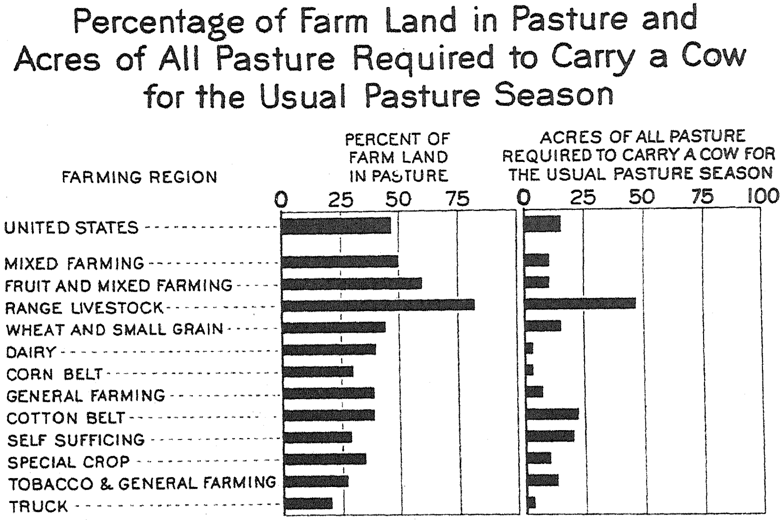

FIG. 2.—Nearly half of the country's farm land is in pasture, but its productivity in terms of feed units per acre is much below that of the land in harvested feed crops. Note the variations by regions in both percentage of land in pasture and its carrying capacity.

of the tillable farm land and pasture 67%. In addition, there is a large area of rough, untillable land which is also used for grazing. In the United Kingdom the "arable" land represents 37% and permanent grass 63% of the presumably tillable area. There is in addition a large extent of untillable land, part of which is used for the grazing of livestock. New Zealand represents the extreme in the dominance of pasture. Only 12% of the land which has been improved in that island country is in crops, whereas tame grass pasture occupies 88% and in addition there is almost an equal area in native grasses which is used for the grazing of livestock.

It has been suggested that the United States should follow the example of these countries which have apparently found that their best economic interest is served by keeping a very high percentage of their land in grass. It is further pointed out that the trends in land use in these countries have been toward more pasture and that this represents a rational adjustment to depressed conditions in agriculture.

There are special conditions affecting the adjustments in these foreign countries, however, which should not be lost sight of. They all have a marine climate, which tends to give pasture a higher comparative advantage than crops. This is partly for the reason that the production and ripening of grain is less successful than in the countries with a continental climate such as our own, and partly that these same climatic conditions are ideally suited to the production of grass and other pasture crops with an extremely high carrying capacity.

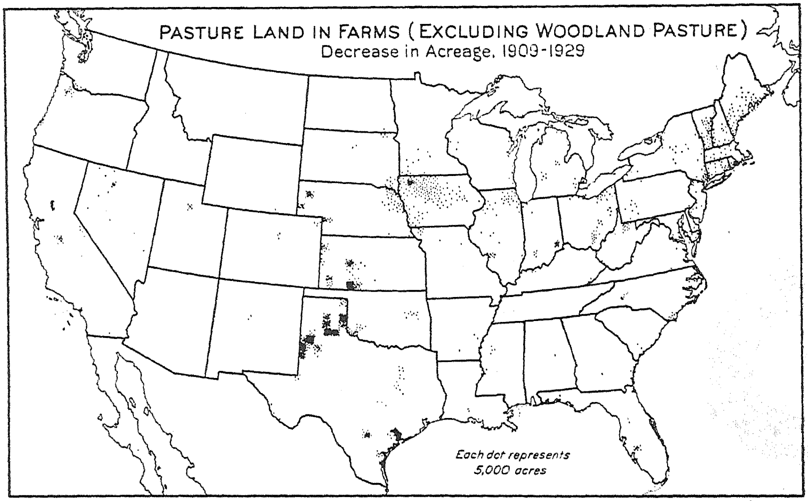

FIG. 3.—Decreases in pasture land in farms in the 20 years ending 1929 were very limited. Grazing land outside farms decreased in this period throughout the Great Plains by the establishment of new farms devoted largely to wheat growing.

In the competition between these different land uses, therefore, it is not surprising that pasture has the ascendency.

In the case of New Zealand there is the additional factor of long distance from important consuming markets which makes it profitable to concentrate the products of the land into high-specific-value animal products which reduce the freight charges to a minimum.

In contrast with the figures from the countries just listed, we may take the example of certain European continental countries. According to the latest available figures from Germany, of the total acreage occupied by crops and pasture 71½% are in crops and only 28½% in pastures. In France these figures are 62% and 38%, respectively. This situation represents the results of a combination of factors including a continental climate, a relatively dense rural population which necessitates intensive use of land, and a type of farm economy characterized by a very high degree of self-containment.

Coming back to a consideration of the place of pasture in our own country, it is worth while to consider the trend in the importance of pasture. Figs. 3 and 4 show geographically the shifts in the use of

land for pasture between 1909 and 1929, as shown by the county census figures for those two years. Each dot in these maps represents 5,000 acres. Fig. 3, showing the areas in which pasture has decreased, reveals that in only a few scattered areas has there been any decrease. Most of this decrease is in the corn belt, notably in northwestern Iowa and adjoining areas, with some scattered decreases in other parts of the corn belt and in the northeastern states. Limited decreases are shown in the panhandle of Texas and in other portions of the Great Plains.

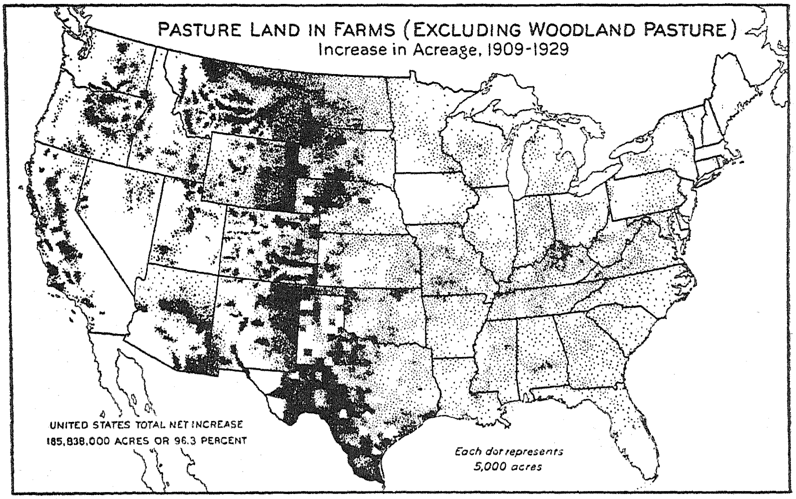

FIG. 4.—Increase in pasture area was general in the 20 years ending 1929. Most of the increase in the western half of the country is nominal rather than real since it represents old grazing land incorporated in new farms. In the eastern part the increase was actual and accompanied a decrease in the area in harvested crops.

The decreases in the corn belt are in those areas favored with the most highly productive soil and most level surface, which give the production of grain a high comparative advantage. The decreases shown in the southern Great Plains represent for the most part the breaking up of grazing land for the production of wheat and cotton in response to factors such as mechanization, which led to the recent remarkable expansion in cropping in this region.

Fig. 4 shows than an increase in pasture acreage has been widespread and of very substantial proportions. Some of this increase, to be sure, is nominal rather than real. Throughout the Great Plains it represents, for the most part, the incorporation into actual farms of public land previously used for grazing, outside the boundaries of farms and hence not reported at all in the earlier census. As a matter of fact, there was a substantial shift out of grazing into crop growing in this region. On the other hand, the increase shown in the eastern half of the country represents a real shift from crops to pasture. The causes of this shift are various. A growing realization of the danger of

soil depletion is one of the most important. Another important one is a real decline in the comparative advantage of feed grains brought about largely by the introduction of tractor power and the accompanying falling off in the use of feeds in the support of workstock. Within this 20 years there was a temporary increase in grain production induced by the war situation which was followed by the resumption of the decline. These changes have been accompanied to some

Percentage of Total Feed Units Produced* From Feed Grains, Hay, Silage, and Pasture in Different Farming Regions

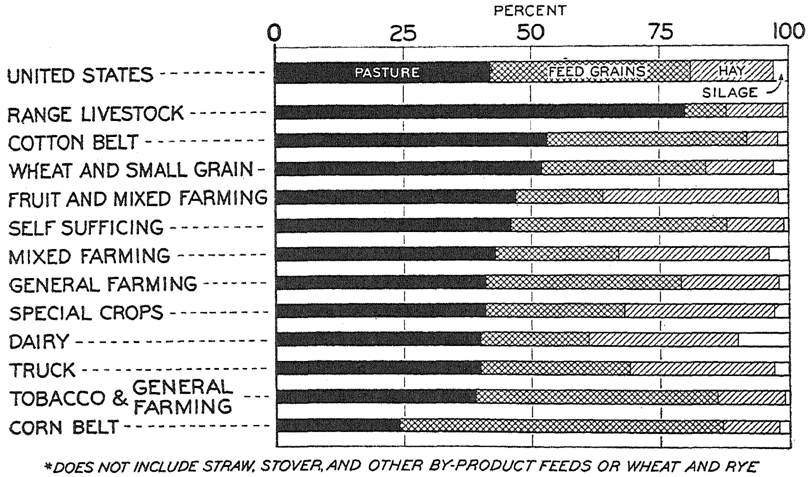

FIG. 5.—Note the small relative importance of pasture as a source of feed in the corn belt as compared with other regions. Hay is also relatively of little importance in the corn belt as compared with feed grains.

extent by an increase in the average size of farms and a decrease in the number of farms, but such changes are not so conspicuous as the major shift from grain to pasture.

The question of whether this progressive shift from crops to pasture in the eastern part of the United States has been continued since 1929 is hard to answer. There has been a substantial reduction in the acreage of all crops, partly due to drought and more recently to the Government's adjustment program, but available figures do not show conclusively that there has been a corresponding increase in pasture. The 1935 census will give comprehensive figures by which the change in pasture over the last 5 years can be measured. It seems probable that the movement which was so apparent up to 1929 was substantially slowed up by the pressure of the back-to-the-land movement.

Considering the importance of pasture as a source of feed, no entirely accurate figures are available. However, we have been making some careful estimates, the results of which are embodied in Fig. 5

which shows the estimated percentage of feed derived from pastures, from feed grains, and from hay and silage, respectively.[3]

Referring again to Fig. 1 in order to get the location of the regions for which data are shown in Fig. 5, we may examine the chart for what it reveals of the relative importance of pasture as a source of feed. It is estimated that for the United States as a whole, 42% of all available feed units are derived from pasture. On this basis of comparison, also, the regional variations are wide, again reflecting, as does the percentage of farm land in pasture, the differing comparative advantage of pasture. The corn belt, with its great natural advantage in grain production, shows by far the lowest position for pasture under existing farm practice.

One of the most important considerations determining the real importance of pasture is its carrying capacity. The second set of bars in Fig. 2 shows this factor, approximately, in terms of the acres per animal unit required to support livestock during the normal pasture season. The highest carrying capacity is to be found in the pastures of the corn and the dairy regions. This is explained by a combination of good soil, favorable climate, and relatively more careful management of pastures. Since pastures in these regions constitute a more important resource in the production of livestock products, they receive somewhat more attention than is characteristic in some of the other parts of the country. Even here, however, the existing average requirement of nearly 5 acres per animal unit reflects the very low quality of much of the pastures in their present condition.

PASTURE IN FARM ECONOMY

Before proceeding to a discussion of pastures in land-use planning, it may be well to consider a number of aspects of the problem from the point of view of the individual farmer. Emphasis in the phrase, "land-use planning," should be upon the word "use". It is the farmer who uses the land. Planning should proceed, therefore, with him and his interest as the focal point.

The first and most patent consideration in the farmer's reaction to the use of pasture, and to proposals for increasing the importance of the place it now holds in farming systems, is the relation of pasture to livestock production. Pasture and hay must obviously be used by livestock if their place in the farming system is to be economically justified; but the influence of the amount and kind of pasture on the amount and kinds of livestock and livestock products is not so obvious. The farmer must be concerned with getting a maximum utilization of all his productive resources; that is, he must get as large a net income as possible, and this means to a considerable extent the largest gross income. If a given proportion of his land must, for physical and economic reasons, be used for pasture, he must determine the kind and amount of livestock which will make best use of it. This depends partly on the nature of the pasture and partly on the relative prices he can get for different classes of livestock and of livestock

[3]Estimates made by R. D. Jennings, Agricultural Economist, Bureau of Agricultural Economics.

products. It also depends on the relation of his pasture resources to the other feeds he can raise or finds it most profitable to raise.

The importance of these relationships may best be illustrated by a consideration of the geographic distribution of the more important livestock enterprises. The dairy industry is largely localized where it is through the elements of soil, surface, and climate which make pastures and the production of hay and other roughage a more profitable use of the land than a system of land use involving higher acreage of feed grains and other grain crops. The farmer must supplement feed from these sources with adequate amounts of concentrates either grown or purchased. The proportion of these which he grows himself is largely determined by physical factors which make growing or buying of concentrates the more profitable.

Contrasted with this situation in the dairy region is that of the corn belt where natural conditions of soil, surface, and climate give production of feed grains a superior economic advantage. Farmers in these two regions have adjusted their livestock enterprises to these natural conditions which have all the essentials of economic forces. The chain of causation tends to run (1) from the nature of the land and climate, which determine the best utilization of the land in terms of specific crop and pasture systems and which yield specific proportions of the different feed elements, to (2) the kind of livestock systems which give the best economic utilization of these feeds. In areas where natural conditions give highest comparative advantage to a system in which carbohydrate feeds—that is, corn and similar grains—have a dominant proportion, the production of meat animals is dominant. In areas where pastures and legumes give the best use value to the land, dairying tends to be dominant.

This states the case only as a generalization. There are hundreds of modifying factors both physical and economic. The important point is that the proposals to increase pasture in specific areas must be made with due consideration of these factors that are so vital to the farmer. This is not to say that adjustments cannot and should not be made. Farmers, like all other humans, have much inertia in their makeup. However, they know that their interest depends in large measure in maintaining an effective balance between pasture and livestock and between pasture and hay and grain in their land-use systems. Their chief weakness probably lies in their failure to recognize and act upon their opportunities to improve the productivity of pasture, and to make its actual competitive power against other land uses rise to its potential level. Much can probably be done in helping farmers to realize the opportunity to get a higher utilization of land through pasture improvement, effective crop rotations involving pasture, and a more effective combination of pasture and roughage with grains in their rations for livestock.

The foregoing leads to a consideration of the relation of pasture to the income and cost side of the farmer's problem. Much has been said and written on the advantage of giving pasture a larger place in the farming system because it means lower costs of production. It is pointed out that pasture requires much less labor per feed unit than do grain crops, and for this reason it has been assumed that a higher

proportion of pasture in the cropping system would be to the economic advantage of the farmer because it reduces his costs. This is an incomplete view of the problem. It is important to consider not only costs per unit but the total volume of output, because both of these things are factors in the farmer's gross and net income.

In a consideration of the cost side of this problem an important distinction between the two outstanding classes of costs in farm production is overlooked. This is the distinction between fixed costs and variable costs. Fixed costs are those that do not rise and fall, at least in the immediate period under consideration, with increases or decreases in the total volume of output. In farming they are represented by such important elements as the interest on investment in farm land, interest and depreciation on farm buildings and other land improvements, interest and depreciation on farm equipment, and the farmer's own labor and that of the family to the extent that it cannot find ready employment outside of the farming business. The variable costs, on the other hand, are those that rise and fall pretty much in proportion to the volume of output. They are represented by such farming costs as fertilizer, hired labor that can be engaged and released as the demand for labor on the farm is greater or less, and other elements which are directly connected with the nature and volume of the output of farm products.

The significance of this classification of costs in terms of the question as to whether it pays to increase or decrease pasture, lies in the fact that the fixed costs cannot be reduced by reducing the output, whereas the variable costs can be so reduced. It is a stubborn fact that fixed costs rather than variable costs dominate in the farmer's production. In systems of farming in which livestock and livestock products are the principal output, our figures show that these fixed costs constitute approximately 75% of the whole. It is obvious, therefore, that a reduction in total output of product means an increase rather than a decrease in the total costs per unit of product; and, so far as this single factor is concerned, if a shift to more pasture means a reduction in the total output, it means a rise in the cost per unit rather than a fall.

The key to the relationship of these considerations to the farmer's reaction to a proposal for more pasture is the relative productivity of pastures as compared with crops. We have no dependable figures on the relative productivity per acre of land in pasture as compared with land in feed grains. Under conditions favorable for the production of alfalfa a higher production of digestible nutrients can be obtained in the form of good alfalfa hay or pasturage than can be obtained from corn under normal yields. This is not true, however, of the average pasture now found on American farms. The great bulk of it is decidedly lower in productivity than the grain crops which could be grown on most of the tillable land which is in pasture or might be put in pasture. Certain rotation pasture crops, such as sweet clover and lespedeza, can compete to advantage with oats and other small-grain feed crops on lands that are suitable for such rotation pasture crops. Some of the bluegrass pasture in the areas of more favorable soil can probably compete on fairly even terms with these grain crops.

However, these high carrying-capacity pastures are the exception rather than the rule in American farming. If pasture is to occupy a more important position and take its place as a means of preventing soil erosion and the depletion of fertility which now presents such an acute problem, it is obviously necessary to build up the productivity of pastures. If they cannot be given a stronger competitive position as compared with grain crops, the proposal to increase the acreage in pastures will encounter almost hopeless resistance on the part of farmers.

These same considerations which have been discussed in terms of costs can probably be more effectively presented in terms of gross and net income from farming. A basic principle in private economy is that of maximum utilization of resources. It means that the farmer's motive in planning the use of his land, labor, and equipment is that of getting the largest possible income from them. Too often, it is true, this motive is considered from the point of view of a short-time return and does not consider adequately the longer time aspects of it. However, it is one of the most stubborn realities in the farming situation. It reflects the basis of the farmer's thinking in the use of his land. He insists on using it in the way which appears to him to promise the maximum income in terms of sale and direct household use of products. Since the fixed elements in his resources so largely dominate, this very largely becomes a matter of maximum gross income.

There is, to be sure, an important collective aspect of this matter in terms of the relation of supply and demand of the various farm products as they affect not only price but total income. The price of the product is one important element which the farmer must consider in reaching his objective of maximum utilization. His consideration of this factor is probably far from adequate because of his lack of understanding of economic forces. Moreover, he is at a fundamental disadvantage as an individual in considering it because his individual action matters so little in the whole alignment of forces which determine price. This is probably the most important reason back of the present agricultural adjustment program. However, even with the present machinery of adjustment, or under conditions which may result from a rational evolution of the present adjustment efforts, the farmer will still have a major responsibility in determining the use he makes of the things he has to produce with. It is important, therefore, that this fundamental motive in farm economy be given due consideration in the proposals for modifying the present position of pastures in American farming.

PASTURES IN RELATION TO LAND USE PLANNING

Let us now turn our attention to the more specific relations of pastures to land-use planning. While the more direct and objective aspect of this relation is that of the need to save the soil from the damaging effects of erosion as well as to build up and preserve an adequate supply of the elements of fertility, other factors of at least equal importance must be kept constantly in view. The ultimate objective in efforts to conserve natural resources is to strengthen the basis for an adequate standard of living. It is important, therefore, to keep in

mind that land is to be saved for use rather than for its own sake. The first consideration is as to how any given proposed measure will affect the economic welfare of the users, both present and future. If, for example, we are going to have in the future more people on the land depending directly on farming for their economic opportunity, this must be taken into account in determining the place we propose to give to pastures in a farm land planning program. Can we utilize the products derivable from an appreciably higher proportion of pasture in a way to realize maximum benefits from our land resources? Can we by this means maintain a production of all of the various agricultural products rationally balanced with the needs of our people?

These questions imply the importance of a well-rounded consideration of all of the legitimate objectives and all of the forces and conditions involved in land-use planning. Difficult as it is to reconcile all of the conflicting interests and considerations, it is not unreasonable to expect that the motive of saving the land and that of realizing an adequate food supply and an ample economic opportunity for those engaged in farming are not antagonistic but can be harmonized into ultimate realization.

We can probably best get at the concrete phases of the relation of pasture to the need for planning future use of land by a study of the present situation in certain so-called problem areas. Fig. 6[4] shows the percentage of the total crop and pasture land in farms in 31 such areas occupied by (1) intertilled crops, (2) non-intertilled crops, and (3) pastures. These areas are all in the eastern and more humid portion of the country.

Inspection of this chart shows that the intertilled, and hence more highly erosive crops, have their highest relative importance in the areas of the cotton belt. A peculiarity of the prevailing types of farming systems in the South is that there is no essential relation between the chief crop, cotton, and livestock. In most other areas where livestock is grown there are important supplementary and complementary relations between the crops and the livestock and hence a more intimate relation between these crops and pasture. This is not true of cotton, since it is not a feed crop and is not essentially tied up with the other activities of the farm except as such activities interfere with the labor demands of the cotton crop. Since cotton must be intertilled and since, as the chart shows, it is so much more important than the non-intertilled crops, there tends to be almost constant use in cotton of the land best fitted for it. The poorer land is naturally relegated to pasture and there is extremely little in the way of crop rotation, particularly as it involves pasture. This condition encourages erosion, augmented to a considerable degree by the fact that the frost-free season amounts to almost the entire year, thus giving the land but little rest from the effects of soil-depleting forces. It is under these conditions that erosion has reached its most advanced stage.

The non-cotton areas shown in the chart have a very low percentage of intertilled crops and a high percentage of pastures. In most of these areas livestock constitutes a tie between crops and pastures and

[4]Data supplied by W. W. Wilcox, Agricultural Economist, Agricultural Adjustment Administration.

tends to minimize the effect of erosion. In most of these areas also non-intertilled crops, mostly hay, which is an erosion preventive,

Percentage of Land in Farms in Intertilled Crops, Other Crops, and Pasture in Selected Farming Regions

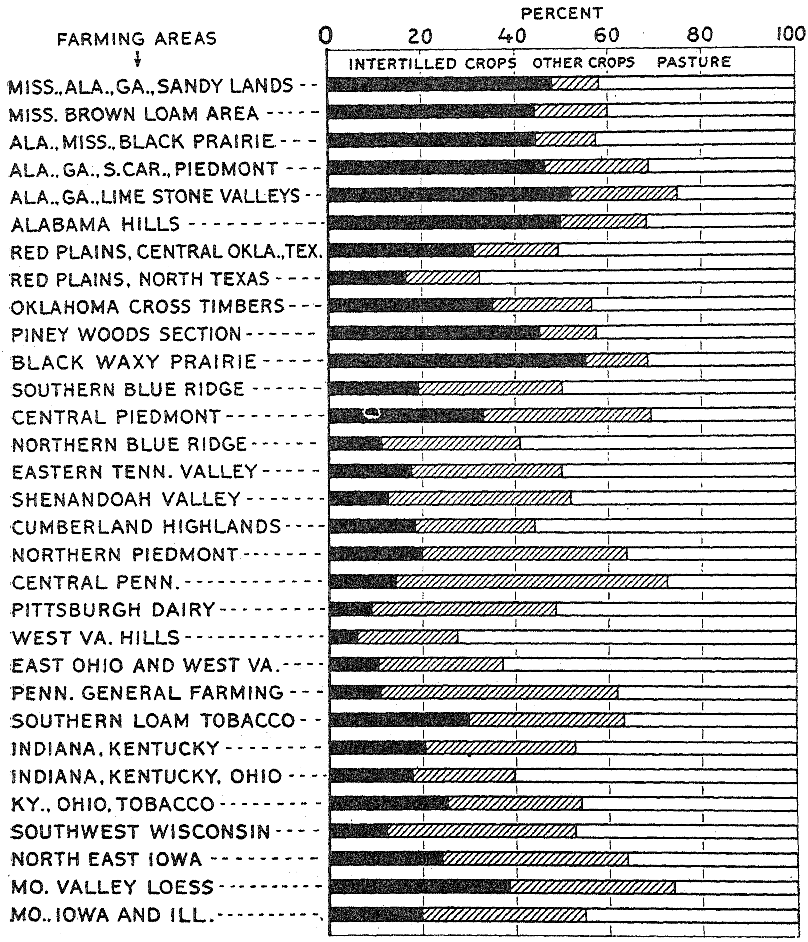

FIG. 6.—Note the high relative position of intertilled crops in the cotton areas as compared with other areas. Note their low position in the hillier areas.

exceed intertilled crops in importance. This means that there is opportunity to keep the intertilled crop area in grass for a part of the rotation period, and thus to minimize the effects of erosion. This system of farming represents a fairly satisfactory adjustment of the cropping and pasture system to the nature of the land.

In the corn belt areas, as shown by the chart, there tends to be a practically even distribution between intertilled crops, non-intertilled crops, and pasture. In this region the winter months are a resting period with reference to erosion forces and there is the closest sort of relation between the two classes of crops grown and the pasture. This relation arises from the important livestock enterprises which are themselves built upon the products of the land. Here, again, a fairly workable adjustment has been achieved.

Going over the different parts of the country once more for brief comments with reference to points of policy and planning on the matter of pasture in the cropping systems, it would appear that the southern problem is largely that of preserving an adequate acreage of crop land and of keeping up its productive quality; this in the face of the difficulties inherent in the farming system and the climate which makes the prevention of erosion very hard. It is probable that as time goes no more emphasis will be placed upon pasture, feed crops, and livestock as a regular though minor source of farm income in the South. However, the natural disadvantages of such a system in this region as compared with the present specialized livestock areas, together with the economic and physical conditions which give cotton its unquestioned ascendency, seem likely to make this solution of the problem only a partial one. Something must be done to preserve the quality of the best cotton lands, which represent the heart of the agricultural resources of the South. The protective possibilities of cover crops is an important element in the solution of this problem and has at least an indirect bearing upon the pasture problem. However, the pasture problem itself centers more specifically in the minor developments already referred to, namely, the growth of feed crops and pasture to support a limited livestock enterprise. In this relation pastures can no longer be looked upon merely as a vacation for worn out land. The questions of their vegetation and management must be taken up not only from the point of view of resuscitating land fertility but in connection with their use as a direct source of income through livestock.

Throughout most of the areas in the North, it seems questionable that any very substantial further movement toward permanently shifting land from crops to pasture can be economically maintained. The solution of the problem in most of these areas would seem to be in the direction of preserving from loss the present crop land without taking it permanently out of crops. This means, for the most part, a greater attention to effective rotations involving legumes which will not only contribute to erosion prevention through providing a larger amount of humus in the soil, but will raise the yields of grain crops so that the same amount, or at least an adequate amount, of grain crops can be raised upon a more limited acreage, thus making it possible to keep a larger proportion than at present of the crop land in soil-conserving crops which, incidentally, means enhanced pasture resources. In most areas, provided suitable soil-building crops can be found, the gain in yield per acre will be enough to compensate for the reduced acreage occasioned by the soil-building crop in the system.

One of the outstanding needs in this connection is the development and popularization of an acid-tolerant legume which will function in the acid-soil areas in approximately the same way that sweet clover is coming to function in the sweet-soil areas. Lespedeza is such a crop, but its present adaptability places a northern limit to its territory somewhere in the southern half of the corn belt. At present the greatest hope for this sort of crop in the northern half of the corn belt and in the dairy region seems to be sweet clover. But the necessity of incurring the heavy costs involved in liming the land to make sweet clover a safe crop is an effective bar to its very wide development, at least under present economic conditions. Probably no greater contribution to the preservation of the soil of the Middle West and the improvement of cropping systems from the point of view of the support of livestock could be made by the agronomists than that of discovering, developing, and popularizing a successful acid-tolerant legume crop which would fit as well into cropping systems on the acid soils of the corn belt and the dairy region as sweet clover does now on the sweet soils.

It has been suggested in many quarters that the increase in pasture land, which is assumed to be needed in certain hilly sections particularly of the southern corn belt and in other areas throughout most of the agricultural portions of the country, might be greatly facilitated by the consolidation of farms, which is assumed to be needed in order to provide an ample economic holding under a condition of the less intensive use of land represented by a pasture system. It seems feasible, from an offhand consideration, to plan for converting considerable areas of hilly farm land, now in relatively small farms, into larger grazing holdings almost to the exclusion of crop growing. When one goes into the factors involved in such a proposal, he encounters what will probably prove to be serious barriers to the successful carrying out of the plan. In the first place, with the back-flow of population from industry to agriculture, we can ill afford to reduce the number of farms. Thousands of farm families with recent farm experience are now living on relief in the cities and towns of our agricultural regions because they have been displaced either as tenants from the farms of landlords who had to move back on their farms to make their own living or through foreclosure of mortgages in the case of owner operators. Presumably, many other thousands of men recently employed in industry but now out of employment, who have an agricultural background, are potential competitors for the opportunity to occupy and run a farm. The case must be made air-tight to justify a reduction in the number of farms under the present conditions. Such justification is probably limited to the plainly submarginal situations where the land is being cleared by the Government to be converted into grazing reserves or consolidated holdings for grazing enterprises. This is particularly exemplified by situations in the Great Plains and other portions of the grazing region.

Another consideration in connection with the proposed consolidation is the question of whether the pasture type of use which is contemplated will support the investment involved in building up a larger holding. Assuming that the present systems of use of such land

yield a larger current income per acre than this land would yield if used entirely or mostly for pasture, we have a competitive element which must be faced in considering the new proposal. Lower use must be accompanied with lower investment per acre in order to be successful. It looks as if it were not possible, in the face of the present competition for farms, to scale down these values to a pastoral-use-returns basis.

CONCLUSION

Summing up the considerations so loosely discussed in the foregoing, we may condense them into four propositions, as follows:

1. The first objective in considering the expanded use of pasture is to make a better present and long-time opportunity for the people on the land. This does not mean merely a place on the land for those unfit for farming; but in the long run, if opportunity for industrial employment continues to be lacking, we must look for a higher percentage of our people on farms solely through the results of less migration from farms to industry.
2. The second objective would seem to be to save the land and make it more productive. This and the first objective, are, in the long run, compatible and harmonious. Their realization involves conservation of land with the use of land.
3. Contrary to the recent assumption that the service of those whose life work had been devoted to means of making the farmer more efficient and his land more productive are now outdated and unneeded, it would seem that the present situation and its demands require more service from these men than ever before. Consequently, the agronomists concerned with the development of pastures and other forage crops have a broader and more important responsibility. They share this responsibility with soil specialists, economists, and many others whose services are needed in meeting the new problem.
4. Finally, in all of this work there is needed, as the condition of a successful outcome, a happy balance between vision and good sense.

SOME LIMITATIONS OF PLANT JUICE ANALYSES AS INDICATORS OF THE NUTRIENT NEEDS OF PLANTS[1]

J. M. POEHLMAN[2]

IN an investigation on the adaptation of Morse and Virginia varieties of soybeans to different soil types, studies were made of the concentrations of nitrates, phosphorous, and potassium in the expressed plant juice of the two varieties. If any differences in concentrations existed, it was thought that they might help to explain the yields of these varieties as manifested on different soil types in different seasons. In addition to the contribution to the problem of varietal differences, an analysis of the data shows many observations on and some limitations of the use of plant juice analyses as indicators of the nutrient needs of plants which are summarized and presented here.

REVIEW OF LITERATURE

Gilbert (4)[3] determined the nitrogen, phosphorous, and potassium of plant extracts by colorimetric methods and found a relationship between the amounts of the elements present in the plant juice and the amounts of the corresponding fertilizing elements added to the soil. Gilbert, McLean, and Adams (6) found concentrations of nitrates, phosphates, and potassium in the plant juice influenced by factors which would limit or inhibit growth, such as deficient amounts of fertilizing elements, and unfavorable weather and cultural conditions. Critical concentrations of nitrates, phosphates, and potassium which should be maintained in the plant sap for optimum yields are suggested by Gilbert and Hardin (5) who found that the current amounts of these elements in plant extracts are influenced materially by the amounts supplied the crops in chemical fertilizers.

The lowering of the freezing point of cell sap by the application of fertilizers to the soil is reported by McCool (9). He suggests that a phosphorous deficiency in the soil may be detected by cell sap studies of crops grown on it. Austin (1) reports that soil type and the application of phosphorous and potassium fertilizer affects the phosphorous and potassium content of the cell sap of soybeans grown in the greenhouse. He believes the soil type to be a greater factor in determining the composition than the application of moderate amounts of fertilizers. McCool and Weldon (10) observed that the application of mineral nutrients to the soil as fertilizers generally resulted in increased concentrations of those elements in the juice and that if one element was limiting, the others would accumulate in the plant juice. Fonder (3) reports that variations were found in the potassium content of the expressed juice from stems and leaves of plants grown on different soil types, but these variations were not related to soil texture. Cook (2) studied the effect of soil type and fertilizer on the nitrate content of the expressed sap of small grains and reports the nitrate content of the sap to be increased by applications of nitrogen fertilizers, but to be decreased by the application of other fertilizers that

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[3]Figures in parenthesis refer to "Literature Cited," p. 206.

increased plant growth. McCool and Weldon (11) report that concentrations of phosphorous, potassium, and calcium in the expressed sap of small grains are reduced by the application of nitrogen fertilizers.

Pettinger (12) found correlations between the nitrate, phosphorous, and potassium concentrations in the expressed sap of corn plants growing on fertilized plats and the fertilizers applied. Three concentration levels of mineral nutrients in the expressed sap are tentatively suggested as indicators of very deficient, moderately deficient, or ample concentrations of nitrogen, phosphorous, and potassium in the soil. In a later paper Pettinger (13) reports an increase in the chlorine content of the expressed sap of corn with the use of chlorine-carrying fertilizers. A residual effect is exerted by the chlorine after 15 years. Pierre and Pohlman (15) report a higher concentration of phosphorous in the exuded sap of corn than in the displaced soil solution. In a later paper they (16) report the phosphate content of the exuded sap of corn grown in the greenhouse to be higher than when the corn is grown in the field. The authors suggest that many factors must be considered before establishing critical concentrations to determine a deficiency of available phosphorous in the soil.

MATERIALS AND METHODS

The plants used in the investigation reported here were Morse and Virginia varieties of soybeans which had been grown in field test plats located on Putnam silt loam, Lebanon silt loam, Oswego silt loam, and Wabash heavy clay. With the exception of the Wabash heavy clay, four fertilizer treatments were applied to each of these soils. The treatments and the rates of applications were as follows: sodium nitrate, 100 pounds; superphosphate, 250 pounds; muriate of potash, 100 pounds; a 4–16–4, 250 pounds; and fine lime, 250 pounds.

In the second season (1933) the plants were grown on the same soil types with the exception of the Wabash heavy clay. No plants from fertilized plats were used for analyses this year except on the Putnam silt loam where the soybeans were grown on the plats used the preceding year and the fertilizer applications repeated.

In making the analyses, plants were secured from five replications on each fertilizer treatment and a composite sample made. From this sample, the juice was pressed out and analyzed for nitrates, phosphorous, and potassium. Plants were secured for analysis when the first pods began to appear to keep the maturity as uniform as possible between the soil types. All samples from a soil type were taken the same day, and conditions were kept as uniform as possible throughout the procedure of sampling and analysis. The entire plants were ground in a food chopper and the juice pressed out with a small "Carver" hand-operated hydraulic press. A pressure of 5,000 pounds was applied and the press cake allowed to drain for 5 minutes. The juice was centrifuged at 2,000 r. p. m. for 10 minutes to remove suspended material. Ten-cc samples were pipetted into evaporating dishes and dried over a steam bath. The samples to be used for phosphate and potassium analyses were placed in an electric muffle furnace and heated for 2 hours at a dull red heat until only a white ash remained.

The nitrate nitrogen in the plant juice was determined by the phenoldisulfonic acid method as reported by Pettinger (12). Preliminary clarification and decolorization of the sap were made according to the methods described by Hill (8). Phosphorous and potassium analyses were made on the samples of plant juice which had previously been ashed. Phosphorous was determined colorimetrically as that soluble in 0.2 N hydrochloric acid after the method described by Zinzadze (18).

Potassium was determined colorimetrically as that soluble in 3% acetic acid after the method described by Herzner (7). So far as the writer knows, no report has been made in the literature regarding the application of these methods of phosphorous and potassium analysis to plant extracts. Soil analyses of available phosphorous and potassium were made colorimetrically by the same methods used for analysis of the plant juice. The soil solutions were obtained by shaking the soil sample with 0.2 N hydrochloric acid.

RESULTS OF EXPRESSED PLANT JUICE ANALYSES

The results of the chemical analyses of the expressed plant juice of Morse and Virginia soybeans grown on different soil types and with varied fertilizer treatments in 1932 are presented in Table 1 and the results for 1933 in Table 2.

TABLE 1.—*Results of analyses of expressed plant juice, 1932.*

Soil type	Variety	Soil treatments				
		Sodium nitrate	No treatment	Super-phosphate	4–16–4 and lime	Muriate of potash
		Nitrate Nitrogen*				
Lebanon......	Morse	69.7	32.3	49.9	28.3	39.5
Lebanon......	Virginia	30.9	24.5	49.9	28.2	39.6
Oswego.......	Morse	23.8	30.7	23.3	28.6	26.0
Oswego.......	Virginia	33.5	27.3	24.4	32.6	38.1
Putnam.......	Morse	32.0	76.2	38.4	40.6	38.9
Putnam.......	Virginia	26.5	49.8	42.5	42.4	40.3
Wabash.......	Morse	——	63.3	——	——	——
Wabash.......	Virginia	——	65.7	——	——	——
		Phosphorous*				
Lebanon......	Morse	106.1	77.5	73.6	77.8	63.7
Lebanon......	Virginia	74.1	64.5	69.8	64.9	71.4
Oswego.......	Morse	117.7	121.8	117.4	109.2	133.4
Oswego.......	Virginia	120.0	131.3	114.1	118.2	115.3
Putnam.......	Morse	78.8	80.4	59.6	64.0	80.0
Putnam.......	Virginia	80.4	77.3	63.5	76.1	122.4
Wabash.......	Morse	——	70.5	——	——	——
Wabash.......	Virginia	——	58.9	——	——	——
		Potassium*				
Lebanon......	Morse	3,956.2	3,989.2	3,866.2	4,415.0	3,821.8
Lebanon......	Virginia	3,501.9	3,617.4	4,144.9	3,471.8	3,938.1
Oswego.......	Morse	1,157.4	944.2	1,344.0	1,971.0	1,806.4
Oswego.......	Virginia	1,606.4	1,459.4	1,344.4	1,971.5	1,732.3
Putnam.......	Morse	4,373.7	4,506.8	3,521.2	3,396.5	3,931.0
Putnam.......	Virginia	3,643.4	4,463.7	3,967.3	2,855.7	3,931.5
Wabash.......	Morse	——	4,769.3	——	——	——
Wabash.......	Virginia	——	4,393.9	——	——	——

*Figures denote nitrates as p.p.m. of N; phosphorous as p.p.m. of P_2O_5; and potassium as p.p.m. of K_2O

TABLE 2.—*Results of analyses of expressed plant juice, 1933.*

Soil type	Variety	Soil treatments				
		Sodium nitrate	No treatment	Super-phosphate	4–16–4 and lime	Muriate of potash
		Phosphorous*				
Lebanon......	Morse	—	54.0	—	—	—
Lebanon......	Virginia	—	54.7	—	—	—
Oswego.......	Morse	—	103.2	—	—	—
Oswego.......	Virginia	—	90.7	—	—	—
Putnam.......	Morse	206.0	139.0	177.3	186.2	167.6
Putnam.......	Virginia	187.5	125.8	146.0	162.1	174.3
		Potassium*				
Lebanon......	Morse	—	10,607.5	—	—	—
Lebanon......	Virginia	—	8,663.6	—	—	—
Oswego.......	Morse	—	4,290.0	—	—	—
Oswego.......	Virginia	—	5,690.0	—	—	—
Putnam.......	Morse	9,240.0	5,575.0	5,960.0	6,970.0	11,050.0
Putnam.......	Virginia	7,895.0	5,935.0	6,310.0	10,655.0	11,145.0

*Figures denote phosphorous as p.p.m. of P_2O_5 and potassium as p.p.m. of K_2O.

ANALYSIS AND DISCUSSION OF RESULTS

An examination of the data in Tables 1 and 2 shows them to be affected by several factors. The controlled factors in the experiment which cause variations in the data may be divided into four groups, *viz.*, varieties, fertilizer treatments, soil types, and years or seasons. The variance due to each of these groups may be segregated, measured, and tested for significance. Within each of these groups the concentrations of mineral elements in the plant juice are affected by a number of conditions whose variance cannot be segregated and measured. These conditions are experimental error in sampling and analysis, variations due to age or maturity of plants, moisture content of plant, rate of growth, soil heterogeneity, and climatic factors, such as light, temperature, rainfall, humidity, and soil moisture. The concentrations of mineral elements in the plant juices may also be altered by interaction of soils and varieties, soils and fertilizer treatments, varieties and fertilizer treatments, and the interaction of each of these with seasons.

The variance due to each of the factors in the experiment—varieties, treatments, soils, and seasons—will be analyzed and discussed. Also the relation of plant juice analyses to soil analyses and its corresponding correlation to yield will be presented.

The results of an analysis of variance (17) applied to the nitrogen, phosphorus, and potassium concentrations in the expressed plant juice of Morse and Virginia soybeans for 1932 are given in Table 3. The analysis takes into consideration only the data from the three soil types, Lebanon, Oswego, and Putnam, as given in Table 1.

TABLE 3.—*Analysis of variance of nitrogen, phosphorous, and potassium concentrations in expressed plant juice of soybeans, 1932.**

Source of variation	Degrees freedom	Sum of squares			Mean square		
		N	P	K	N	P	K
Total variance.....	29	.4596	1.7579	40.5361	——	——	——
Variance between means of varieties..	1	.0078	.0001	.0612	.0078	.0001	.0612
Variance between means of treatments	4	.0147	.1003	.1673	.0037	.0251	.0418
Variance between means of soils.....	2	.1053	1.2558	36.2532	.0526	.6279	18.1266
Variance due to interaction:							
Varieties—soils...	2	.0257	.0894	.2821	.0128	.0447	.1410
Varieties — treatments..........	4	.0397	.0304	.4855	.0099	.0076	.1214
Soils—treatments.	8	.2169	.1820	2.7016	.0271	.0228	.3377
Remainder—experimental error.......	8	.0495	.0999	.5852	.0062	.0125	.0731

*Decimal points were moved two places to the left for calculations of N and P and three places to the left for calculations of K.

VARIANCE BETWEEN MEANS OF VARIETIES

By the analysis of variance we are able to segregate for that season the variance in the concentrations of elements in the plant juice due to varieties, soils, fertilizer treatments, and to interaction. We may then test the significance of the variance in the concentrations attributed to differences in varieties by comparing its mean square with the mean square of the remainder which we attribute to experimental error and other uncontrolled factors in the experiment. An examination of the mean squares in Table 3 reveals that the variance due to varieties is not significantly different from the variance due to experimental error. This signifies that we cannot measure any significant differences between Morse and Virginia varieties of soybeans by chemical analyses of the expressed plant juice for nitrogen, phosphorous, or potassium.

A comparison of the mean squares of the variance due to interaction with the mean squares of the remainder reveals no significant differences for either nitrate, phosphorous, or potassium concentrations. This means that the measured differential effect between the varieties and the different soil types and fertilizer treatments is not significant.

VARIANCE BETWEEN MEANS OF FERTILIZER TREATMENTS

No significant differences may be found by comparing the mean squares of the variance between means of treatments and experimental error. This indicates that we cannot measure any appreciable effect of fertilizer treatments on the concentrations of nitrates, phosphorous, and potassium in the expressed plant juices of soybeans in 1932. These are contrary to the results of previous investigators (5, 1, 10, 2, 11, 12, 13, 16).

In measuring the effect of fertilizer treatments by plant juice analysis, it is important to distinguish between plants grown in pot experiments (4, 1, 10, 16) and in field plats, and also between the time and rates of fertilizer applications. Pohlman and Pierre (16) report higher concentration of phosphorous in the exuded sap of plants grown under greenhouse conditions than when the plants are grown on the same soils under field conditions. With extremely high rates of fertilizer applications (6, 9) we may expect a greater effect on the plant juice analyses than with moderate applications. When fertilizers have been applied to field plats over a period of years, an analysis of the plant juice measures the residual effect of the fertilizer (2, 12, 13) as well as the effect of the current treatment.

It is possible that the fertilizing elements did not go into solution in the soil in time appreciably to affect the plant juice analysis in the 1932 season. On the Putnam silt loam the fertilizer applications made in 1932 were repeated before planting in 1933. The results are illustrated in Fig. 1. In the plant juice analysis made in 1933 on this soil type not only the effect of the current fertilizer applications, but also the residual effect from the previous year is being measured. These results indicate that moderate fertilizer treatments will materially affect the plant juice analyses if they have ample time materially to affect the soil solution. The variance in the concentrations from "no treatment" plats as well as a corresponding variance from the fertilized plats between the years may be attributed to differences in the climatic and soil moisture conditions of the two seasons.

VARIANCE BETWEEN MEANS OF SOILS AND BETWEEN MEANS OF YEARS

In Table 4 are recorded the results of an analysis of variance of the expressed plant juice data for 1932 and 1933. By this analysis we are able to segregate the variance due to differences in soils and to the differences in seasons and measure the effect of these factors on the concentration of phosphorous and potassium in the expressed plant juice. This analysis of variance embodies the data from the plats on Lebanon, Oswego, and Putnam soils in 1932 and 1933.

A comparison of the mean square attributed to the variance between the means of soils and the mean square of the error (within classes) shows a large difference which may be regarded as highly significant. This means that the phosphorous and the potassium concentrations in the plant juice differ significantly with the different soils upon which the plants were grown and that soil type is an important factor in determining the concentration of these elements in the plant juice. This is in agreement with the work of previous investigators (1, 2, 3, 16).

Part of the variance attributed to soil type must be regarded as due to climatic differences between the different fields. The field plats are located on different soil types as indicated and any climatic differences between these fields which would affect the general rate of growth or metabolism of the plants would be measured along with the soil differences. That this variance is probably small will be

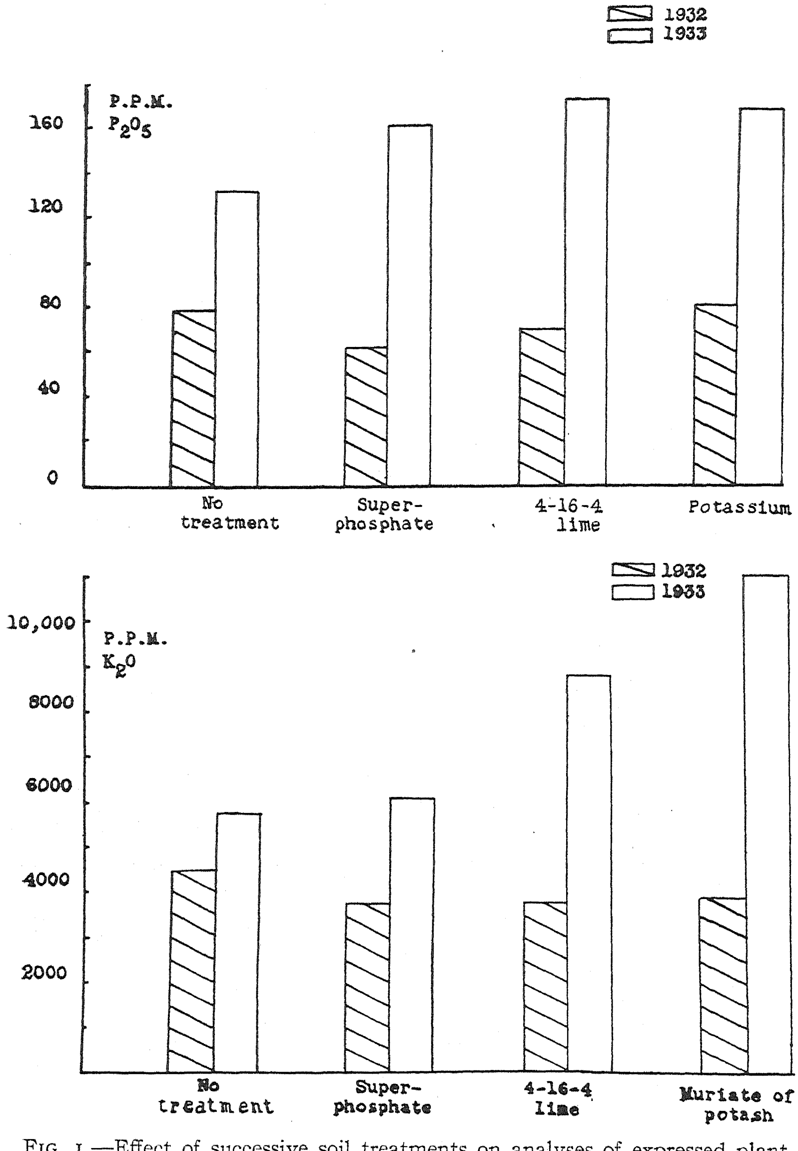

FIG. 1.—Effect of successive soil treatments on analyses of expressed plant juice of soybeans grown on Putnam silt loam, 1932 and 1933.

shown, however, by the relation of phosphorous and potassium concentrations in the plant juice in succeeding years and the relation of plant juice analyses to soil analyses.

"Within a soil type," the variance between means of different seasons may be measured by comparing its mean square with the

mean square of the experimental error (within classes). A comparison of these mean squares in Table 4 shows that climatic differences between years is a very significant factor influencing the concentrations of phosphorous and potassium in the plant juice of soybeans. Gilbert,

TABLE 4.—*Analysis of variance of phosphorous and potassium concentrations in expressed plant juice of soybeans, 1932 and 1933.**

Source of variation	Degrees freedom		Sum of squares		Mean square	
	P	K	P	K	P	K
Total	42	11	7.24	79.4931	—	—
Variance within classes (experimental error)	37	6	.80	3.1356	.022	.5225
Variance between:						
Means of soils	2	2	2.12	26.3802	1.06	13.1901
Means of seasons	1	1	2.48	39.5321	2.48	39.5321
Interaction	2	2	1.84	10.4458	.92	5.2229

*Decimal points were moved two places to the left for calculations of P and three places to the left for calculations of K.

McLean, and Adams (6) observed that any limiting condition, such as unfavorable weather conditions, which would affect the metabolism of the plant would be reflected in the plant juice analyses. During the growing season in 1932 the total rainfall was 9.31 inches and in 1933, 2.88 inches. This explains the higher concentrations of potassium in the juice the second season.

RELATION OF PLANT JUICE ANALYSES IN SUCCEEDING YEARS TO SOIL ANALYSES AND TO YIELD

By an analysis of variance we have found that the concentrations of phosphates and potassium in the plant juice of soybeans varies significantly "between soils" and "between years." In the data analyzed, the variance between years was more pronounced than the variance between soils. If we are to use comparative plant juice analyses as an indicator of the nutrient needs of plants growing on different soil types as has been suggested by several investigators (1, 3, 15, 16, 2, 11), we should determine if the relation between soils is constant when we also have a large variance due to years. Otherwise the effect of climate might outweigh the effect of soils in the plant juice when comparing results of different years.

In Fig. 2 are shown the relations of the concentrations of phosphorous and potassium in plant juice from plants grown on Oswego and Lebanon soil types in succeeding years and the corresponding relation to soil analyses. We see that in both seasons the plant juice of soybeans grown on the Oswego soil has a higher concentration of phosphates than the plant juice of soybeans grown on the Lebanon soil and that a soil analysis shows the Oswego soil also to be higher in available phosphorous than the Lebanon soil. With the potassium the reverse is true, the plant juice from soybeans grown on the Leb-

anon soil having the highest concentration for both seasons, and the Lebanon soil also having the highest concentration of available potassium.

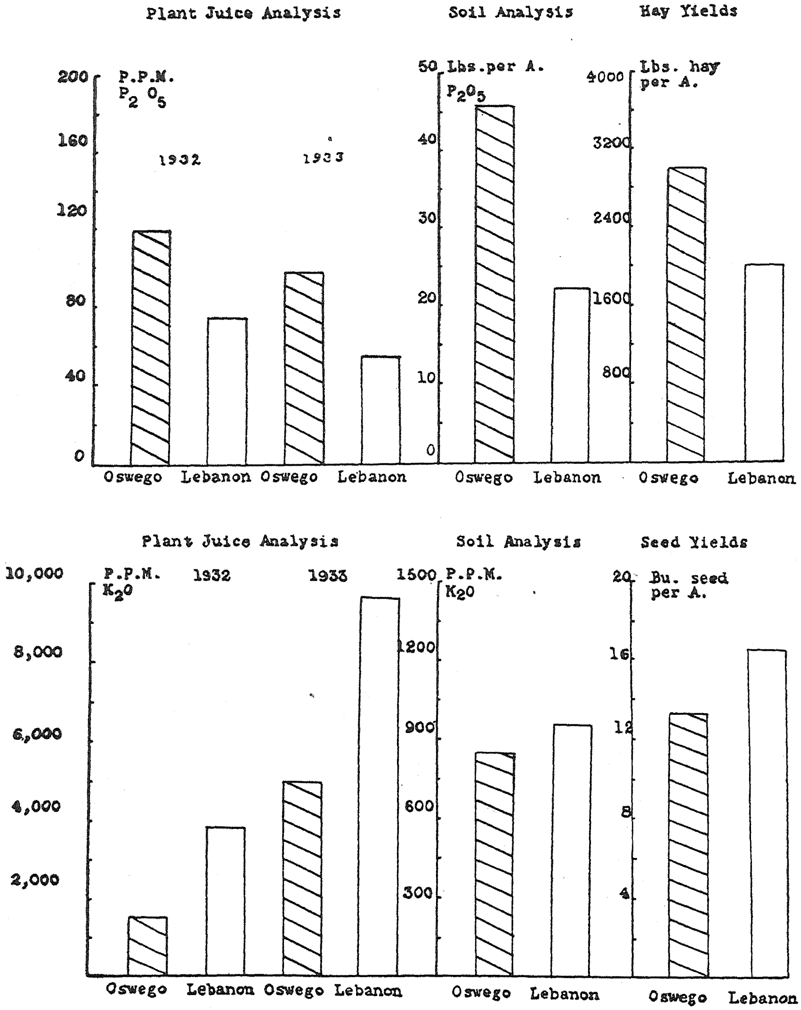

FIG. 2.—Relation of plant juice analyses to soil analyses and to yield on Oswego and Lebanon silt loam.

If plant juice analyses are to be used as an indicator of the fertilizer needs of plants growing on different soils, they should also be correlated to yield (2, 5, 6, 12, 16). This relation is shown in Fig. 2. Here there is an indication that a correlation may exist between the phosphate analysis of plant juices and hay yields, and between the potassium analyses of plant juice and seed yields of soybeans on these

soil types. This will be further analyzed and discussed under an analysis of co-variance.

CO-VARIANCE OF PLANT JUICE ANALYSES AND YIELD

The results of analyses of co-variance (17) applied to the concentrations of phosphorous and potassium in the plant juice and the yields of soybeans grown on Oswego and Lebanon soil types are given in Table 5.

TABLE 5.—*Analysis of co-variance of correlation coefficients of yields of hay and seed to concentrations of phosphorous and potassium in the expressed plant juice of soybeans grown on Oswego and Lebanon soil types.*

Source of variance	Degrees of freedom	Correlation coefficient	Regression coefficient	Odds
Hay Yields to Phosphorous				
Between soils (within treatments and varieties)	9	.742	.85	216:1
Within soils (between treatments, within varieties)	15	—.520	—1.10	66:1
Seed Yields to Potassium				
Between soils	7	.423	.081	6.4:1
Within soils	13	.460	.484	24:1

The correlation coefficient of the phosphorous concentration in plant juice and the hay yield between means of soils is .742 with a regression coefficient of yield on concentration of phosphorous of .85. This means that an increase of 1 p.p.m. of P_2O_5 in the concentration of phosphorous in the plant juice of plants on the Oswego soil over those on the Lebanon soil will be accompanied with a corresponding increase in yield of hay on the Oswego soil of 0.85 pound per acre. Within the soils there is a negative correlation of —.520 and a negative regression coefficient of yield on concentration of phosphorous of —1.10. This means that an increase of 1 p.p.m. of P_2O_5 in the phosphorous concentration .of the plant juice from any plat on the Oswego or Lebanon soils will be accompanied by a decrease of yield on that plat of 1.10 pounds of hay per acre.

A reasonable interpretation of these results may be made. The concentrations of phosphorous and potassium in the plant juice represent an accumulation of these mineral elements. In a comparison of plants grown on soils low and high in nutrient elements, we would expect an increase in the concentration of mineral elements in the plant juice (9) with an increase of these elements in the soil as well as a corresponding increase in yield. This is the relation found above "between the means" of the Oswego and Lebanon soils. "Within soils" the hay yields tend to decrease with increases in the phosphorous content of the plant juice. Any condition which limits the rate of metabolism of the plants will cause an accumulation of the mineral elements in the juice (6). The negative correlation coefficient indicates the limiting factor in this case to be other than the supply of

available phosphates. When this limiting factor affects the metabolism of the plant, the yield will be limited and the phosphorous will accumulate in the juice. This accounts for the negative regression of yield on phosphorous concentration.

The correlation coefficient of potassium concentration in plant juice and seed yields "between means of soils" is .423 with a regression coefficient of .081 bushel for each increase in potassium concentration of 1 p.p.m. of K_2O. This means that an increase of the potassium concentration of 1 p.p.m. of K_2O will be accompanied by a corresponding increase in yield of 0.081 bushel between the means of the two soil types. "Within the soils" the correlation coefficient is .460 with a regression coefficient of .484 bushel for each increase in potassium concentration in the plant juice of 1 p.p.m. of K_2O. The "odds" indicate that the correlation of hay yields and phosphorous concentrations may be regarded as significant, while the correlation of seed yields to potassium concentrations could not be so regarded. These correlations illustrate the variety of factors which affect and the limitations involved in setting up a laboratory method of measuring plant juice concentrations to determine the nutrient needs of plants.

ESTABLISHMENT OF CRITICAL CONCENTRATIONS FOR PLANT JUICE ANALYSES

Certain investigators (5, 12) have suggested the use of critical concentrations of nitrates, phosphorous, and potassium to be maintained in the plant juice as indicators of nutrient needs of plants. The results presented in this paper, i.e., the relation of plant juice analyses on different soils in succeeding years, relation to soil analyses, and the correlation to hay and seed yields, suggest that plant juice analyses may serve as an indicator of the nutrient needs of plants on different soils. It is doubtful, however, if critical concentrations of the mineral elements in the plant juice may be set up, as has been suggested, to indicate the relative supply of these minerals in the soil. The variance in plant juice analysis due to fertilizer treatments, the variance due to different soil types, and the significantly large variance due to seasonal factors makes the establishment of critical concentrations very problematical.

SUMMARY

No significant differences could be distinguished through an analysis of variance in the concentrations of nitrates, phosphorous, and potassium in the expressed plant juice of Morse and Virginia varieties of soybeans. Moderate fertilizer treatments had no significant effect on these concentrations the first season. In the second season, where the fertilizer treatments were repeated, relations between the treatments and phosphorous and potassium concentrations were found.

Soil type and climatic differences due to seasons were both important factors in determining the concentrations of phosphorous and potassium in the plant juice. The variance due to season was larger than the variance due to soils. The phosphorous and potassium con-

centrations in the plant juice in succeeding seasons held the same relation between Oswego and Lebanon soils and were related to the concentration of these elements in the soil.

Correlations were calculated between the concentrations of phosphorous in the plant juice and the yields of hay and the concentrations of potassium in the plant juice and yields of seed. An analysis of variance and co-variance applied to the data shows the correlation coefficients and the regression of yield on concentrations of phosphorous and potassium in the plant juice.

LITERATURE CITED

1. AUSTIN, RUSSELL HAYDEN. The effect of soil type and fertilizer treatment on the composition of the soybean plant. Thesis presented for the degree of doctor of philosophy, Soils Dept., Mich. State College. 1928.
2. COOK, R. L. Effect of soil type and fertilizer on nitrate content of the expressed sap and the total nitrogen content of the tissues of small grains. Jour. Amer. Soc. Agron., 22: 393–408. 1930.
3. FONDER, J. F. Variations in K content of alfalfa due to stage of growth and soil type and the relationship of K and Ca in plants grown upon different soil types. Jour. Amer. Soc. Agron., 21: 732–750. 1929.
4. GILBERT, B. E. The adaptation of certain colorimetric methods to the estimation of nitrates, phosphates, and potassium in plant solutions. Plant Physiol., 1: 191–199. 1926.
5. ————, and HARDIN, LEO J. The current mineral nutrient content of the plant solution as a possible means of chem. control of optimum fertilization. Jour. Agr. Res., 35: 185–192. 1927.
6. ————, McLEAN, F. T., and ADAMS, W. L. The current mineral nutrient content of the plant solution as an index of metabolic limiting conditions. Plant Physiol., 2: 139–151. 1927.
7. HERZNER, ROBERT A. Kalium and nitrit bestimmung in stark verdunnten losungen. Biochem. Zeitschr., 237: 129–132. 1931.
8. HILL, H. H. Plant juice clarification for nitrate N determinations. Science, 71: 540. 1930.
9. McCOOL, M. M. Relation of soil to plant cell sap. Mich. Agr. Exp. Sta. Quart. Bul. 9: 60–64. 1926.
10. ————, and WELDON, M. D. Effect of soil type and fertilization on the composition of the expressed sap of plants. Jour. Amer. Soc. Agron., 20: 778–792. 1928.
11. ————, ————. The effect of sodium nitrate on the composition of the expressed sap of small grains. Jour. Amer. Soc. Agron., 22: 434–437. 1930.
12. PETTINGER, N. A. Expressed sap of corn plants as an indicator of nutrient needs. Jour. Agr. Res., 43: 95–119. 1931.
13. ————. Effect of fertilizers on the chlorine content of the sap of corn plants. Jour. Agr. Res., 44: 919–931. 1932.
14. ————, and THORNTON, S. F. A comparison of the Neubauer, plant-sap analysis, and Hoffer stalk-test methods for determining the nutrient supply of soils. Jour. Amer. Soc. Agron., 26: 547–561. 1934.

15. PIERRE, W. H., and POHLMAN, G. G. Preliminary studies of exuded plant sap and the relation between the composition of the sap and the soil solution. Jour. Amer. Soc. Agron., 25: 144–160. 1933.

16. POHLMAN, G. G., and PIERRE, W. H. The phosphorous concentration of the exuded sap of corn as a measure of the available phosphorous in the soil. Jour. Amer. Soc. Agron., 25: 160–171. 1933.

17. SNEDECOR, GEO. W. Calculation and Interpretation of analysis of Variance and Co-variance. Ames, Iowa: Collegiate Press, Inc. 1934.

18. ZINZADZE, R. Neue methoden zur kolorimetrischen bestimmung der phosphor und arsensaure. Zeitschr. f. Pflang., Dungung, und Bodenkunde, A. 16: 129–184. 1930.

GENETIC RELATIONS OF THREE GENES FOR ANTHER COLOR IN COTTON[1]

G. N. STROMAN[2]

THE large number of chromosomes, 26, of the New World cottons should produce many series of genes for certain characters of the cotton plant. The present paper presents interrelations of three genes for anther color found in a natural cross of an Upland type of cotton, *Gossypium hirsutum*, with a Peruvian type, *G. barbadense*.

REVIEW OF LITERATURE

Balls (1)[3] studied anther color and obtained from an F_2 of an Upland-Egyptian cross a 1:2:1 ratio of yellow, intermediate, and buff. Kearney (5) obtained a similar result from the same type of cross but stated that the F_2 had a bimodal frequency. McLendon (6) studied anther color in an Upland-Sea Island cross but came to no definite conclusions as to number of genes involved.

Harland (3) in several crosses of New World cottons, including crosses of Upland-Upland and Upland-Peruvian, studied pollen color (the same as anther color) and concluded that there was one basic gene for yellow and white pollen which he called *P*. In this study pollen color was divided into nine different grades from dark yellow to white. However, in some of the F_2's of the crosses the segregation into two or more widely different colors was very distinct. In some of the crosses the segregation was not so pronounced. Also, there was some evidence of an intensifier gene, *Q*, which caused the yellow to be of a deeper color. Harland (4) gives a summary of genetic work done on cotton.

MATERIALS AND METHODS

The material from which these studies were made came from a hybrid plant which originated at one of the government stations about 1924. The seed of this plant was given to the writer and was planted in 1929 under the cotton breeding No. 179.

The segregation of yellow and white (or cream) was very distinct in the families referred to below. However, yellow included the pale yellows, but the distinction of yellow or pale yellow from cream or white was very clear. Throughout this treatment yellow when spoken of includes the pale yellow, and white includes the cream. In reality the white anthers in most cases are cream.

The parentage of No. 179 is not definitely known, but several government cotton men who saw it growing were very positive in saying that it was an Egyptian-Upland cross or *G. barbadense* x *G. hirsutum*. The progeny of this plant segregated for nearly all the characters of the cotton plant, but none that was noted was inherited in a simple manner.

In 1929, 1930, and 1931 the flowers of the families and progenies reported herein were tied with a string before they opened. The large numbers of plants self-pollinated in 1930 and 1931 made it impossible to self-pollinate all flowers, for in

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[3]Figures in parenthesis refer to "Literature Cited," p. 215.

the usual course of the procedure some were overlooked. However, it is known that only a small percentage was left open, and of course these in only a small percentage of cases would be accidentally crossed. Transfer of pollen from one flower to another would occur only by means of insects.

The goodness of fit method, along with Fisher's (2) X^2 tables, was used to determine the significance of the deviations, observed from expected, of the several types of ratios.

THE HYPOTHESIS

The data seem to show the presence of three genes. Two of these genes are for yellow color and the third is an inhibitor of either one of the others when they are not present together. The two genes for yellow color will be referred to as *P* and *B* and the inhibitor as *I*.

The data will be discussed from the standpoint of types of ratios and their proportion to show that the above hypothesis does fit the results obtained. The F_3 segregation of the yellow-anthered parents should show six types of F_2 genotypes. The ratios of such genotypes should be 10 pure yellow; 8, 3 yellow: 1 white; 4, 15:1's; 8, 13:3's; 4, 9:7's; and 8, 42:22's. From white parents there should be in addition to the pure white progenies, two types of progenies, one giving 3 white: 1 yellow and another type giving 13 white: 3 yellow.

THE DATA

The progeny of the parent plant, family 179, segregated into 91 yellows and 41 white anthers. This is a deviation of only 4 to fit a 42 : 22 ratio. The 42: 22 ratio is according to the hypothesis of two genes for yellow color accompanied by an inhibitor gene as stated above. In the initial year the whites were in part called pale yellow. The following year these were called cream. The yellows were separated into two grades, yellow and pale yellow; but the difference between the yellow, including pale yellow, and the so-called whites or creams, was very distinct.

The segregation the following year (F_3) of the individual progenies is found in Table 1. The totals of the segregating progenies from yellow-anthered parents are as follows: The 42 yellow: 22 white ratio is 179:89; the 3 yellow: 1 white ratio, 78:26; the 13:3 ratio, 33:8; the 9:7 ratio, 68:45; and the 15:1 ratio, 62:5. The largest deviation of observed to expected occurs in the 9:7 ratio, but even here the P = .30 to .50. There may be some doubt of separating 3:1 progenies from 13:3 progenies or of 15 : 1's and the pure yellow progenies even though their total observed fit their respective ratios. Throwing together the kinds of progenies just mentioned the ratio of genotypes should be 14, pure yellow and 15 : 1's; 16, 3 : 1's; and 13 : 3's; 4, 9 : 7's; 8, 42 : 22's, a total of 42 genotypes. The observed gave 8 : 6 : 4 : 5, a total of 23 progenies. The goodness of fit of calculated to observed gave for these genotypes a P = .30 to .50.

This genotypic test is in line with the hypothesis. In this test the pure yellows and the 15 yellow to 1 white progenies are thrown together, owing to the fact that there are small numbers in the progenies and natural crossing in the field might naturally give numbers similar to a 15 : 1 ratio. The 3 : 1 and 13 : 3 ratio progenies are

totaled together for the same reason. However, the P calculated on the ratio of progenies with all the ratios separated was nearly as large as that shown.

TABLE 1.—*Segregation as to anther color of the 179 family.*

Plant No.	Anther color		Total	Family No.	Ratio	
	Yellow	White			Yellow	White
			From Yellow Parents			
36*	28	10	38	34	3	1
2	24	7	31	35	3	1
4	25	16	41	36	9	7
5	37	18	55	37	42	22
9	32	17	49	41	42	22
10	12	8	20	42	9	7
11	25	6	31	43	13	3
15	41	20	61	46	42	22
18	2	7	9	49	1	3
19	24	16	40	50	9	7
20	16	1	17	51	15	1
23	8	0	8	54	Pure?	—
29	17	1	18	57	15	1
27	38	1	39	58	Pure	—
35	31	0	31	62	Pure	—
49	7	1	8	65	15	1†
54	10	1	11	67	15	1
56	11	4	15	68	3	1
58	52	26	78	69	42	22
58B	8	0	8	70	Pure	—
59	7	5	12	71	9	7
79	8	0	8	75	Pure?	—
99	17	8	25	79	42	22
112	15	0	15	82	Pure?	—
132	8	2	10	85	13	3
76	19	2	21	92	15	1
			From White Parents			
1	15	5	20	31	3	1
31	0	117	117	33	—	Pure
8	3	19	22	39	—	Pure
7	3	33	36	40	—	Pure
16	2	51	53	47	—	Pure
17	0	13	13	48	—	Pure
22	1	70	71	53	—	Pure
26	0	8	8	56	—	—
28	2	48	50	59	—	Pure
30	7	76	83	60	—	Pure?
37	4	46	50	63	—	Pure
42	3	42	45	64	—	Pure
64	10	15	25	72	1	3?
110	7	49	56	81	3	13
118	0	27	27	83	—	Pure
125	2	16	18	84	1	3‡

*No record of parent color.
†Not included in genotypic test.
‡Next year's progeny segregated giving dominant white, 3 whites: 1 yellow.

To verify the hypothesis further, evidence of the plantings in 1931 will be presented. These plantings included family No. 69, from 179–58,

which gave a 42 : 22 ratio of yellow to white anthers. This is a duplication of the 179 family, and the data are shown in Table 2. The totals in the several segregating ratios are as follows:

	Yellow	White	Total	Progeny numbers and P
Ratio	42	22	64	69–3, 11, 20, 24, 37, 39
Observed	719	349	1,068	P = .20 to .30
Ratio	3	1	4	69–1, 2, 4, 42, 59, 66, 78, 80
Observed	538	199	737	P = .20 to .30
Ratio	9	7	16	
Observed	150	88	238	69–5, 8
Calculated	134	104	238	P = .02 to .05
Ratio	15	1	16	
Observed	101	7	108	69–17, 19
Calculated	101.25	6.75	108	
Ratio	13	3	16	
Observed	412	95	507	69–25, 27, 30, 54, 68
Calculated	412	95	507	

The fit of calculated to observed is good on all types of ratios except possibly the 9 : 7 ratio. However, the genotypic test where the ratio of progenies should be 14, pure yellow and 15 : 1's : 8, 3 : 1's : 4, 9 : 7's : 8, 13 : 3's : and 8, 42 : 22's gave for the observed, respectively, 8 : 8 : 2 : 5 : 6 which is a total of 29 progenies. A P = .70 to .80 shows good agreement of calculated to observed. It will be noted that only the progenies of parents with yellow anthers are summarized, because the progenies of white-anthered parents were discriminated against by reason of the fact that yellow color was believed to be dominant to white. However, it is seen in Tables 1 and 2 that some of the progenies of plants with white anthers did segregate. The 3 white to 1 yellow and the 13 white to 3 yellow are according to the hypothesis. There are several that apparently give a 15 white to 1 yellow ratio, which is not according to the hypothesis and could have been caused by accidental crossing in the field. It has been noted that the self-pollination of these progenies was not 100%. The writer is of the opinion that this is the cause of the aparently 15 white : 1 yellow ratio. However, it might be attributable to a modifying gene not accounted for here.

In Table 2, plant No. 11 was recorded as of a cream color, but it is the writer's opinion that this was a mistake and probably caused by recording the color from a flower before the pollen was ripe. Another questionable progeny will be found in Table 1, plant No. 18, which gave a 3 white : 1 yellow segregation.

FURTHER EVIDENCE

The 1931 planting consisted also of the progeny of plant No. 19 of family 179 under genetic family No. 50, plant No. 36 of family 179 under family No. 34, and plant No. 125 of family 179 under family No. 84. Table 1 shows the segregation of the parent progenies. The 50 family

gave a 9 yellow : 7 white ratio; the 34 family, a 3 yellow : 1 white ratio; and the 84 family the reverse of the latter, giving a 3 white : 1 yellow ratio.

TABLE 2.—*Segregation of anther color of the progenies, the color of the parent plant, and family number indication of the genotype in the 69 family.*

Plant No.	Anther color		Total	Ratio	
	Yellow	White		Yellow	White
			From Yellow Parents		
1	71	27	98	3	1
2	141	49	190	3	1
3	55	30	85	42	22
4	23	8	31	3	1
5	29	17	46	9	7
8	121	71	192	9	7
11	144	76	220	42	22
17	43	3	46	15	1
19	58	4	62	15	1
20	199	93	292	42	22
22	230	2	232	Pure	—
24	82	35	117	42	22
25	140	36	176	13	3
27	128	25	153	13	3
30	47	11	58	13	3
32	39	2	41	Pure	—
36	73	2	75	Pure	—
37	122	59	181	42	22
39	117	56	173	42	22
42	116	47	163	3	1
45	101	2	103	Pure	—
54	68	16	84	13	3
59	43	15	58	3	1
66	33	12	45	3	1
68	29	7	36	13	3
70	14	0	14	15:1	Pure yellow?
73	17	2	19	Pure?	—
78	68	24	92	3	1
80	43	17	60	3	1
			From White Parents		
14	42	224	266	3	13
16	0	263	263	—	Pure
21	12	129	141	—	Pure
26	2	201	203	—	Pure
28	3	87	90	—	Pure
33	3	71	74	—	Pure
50	7	84	91	—	Pure
64	10	32	42	1	3
71	1	31	32	—	Pure
75	3	93	96	—	Pure

Tables 3 and 4 give the detailed data on the progenies of these families. According to the hypothesis, two types of ratio should be found from the progenies of family 50, i.e., 9 : 7 and 3 : 1; and the calculated to observed on the segregating progenies show the proportion to be excellent. The theoretical ratio of genotypes should be 1

pure yellow to 4, 9 : 7 progenies to 4, 3 : 1 progenies. There were found a total of 1 : 5 : 8, respectively, which gave of calculated to observed a P equaling .50 to .70.

In Table 4 is found a summary of the data of family 34, the calculated to observed giving a P = .20 to .30. The ratio of homozygotes to heterozygotes of 1 : 2 is realized in 5 homozygotes (all yellow) and 9 heterozygotes (3 yellow : 1 white). Seed from only yellow-anthered plants were planted in this family.

TABLE 3.—*Segregation of anther color in family 50 whose parent gave 9:7 ratio of yellow to white anther.*

Plant No.	Anther color		Total	Ratio	
	Yellow	White		Yellow	White
From Yellow Parents					
5	31	19	50	9	7
6	15	12	27	9	7
8	22	7	29	3	1
10	14	8	22	9	7
13	17	14	31	9	7
17	29	9	38	3	1
21	39	25	64	9	7
26	36	11	47	3	1
29	59	21	80	3	1
30	52	23	75	3	1
33	17	7	24	3	1
36	6	0	6	Pure	–
37	19	7	26	3	1
39	46	9	55	3	1
From White Parents					
3	1	65	66	–	Pure
7	0	70	70	–	Pure
12	0	22	22	–	Pure
15	2	35	37	–	Pure?
18	3	43	46	–	Pure?
22	0	9	9	–	Pure

The summary of data on the 84 family is also shown at the bottom of Table 4. In this family a reversal of dominance occurred. The total of 3 white : 1 yellow anther progenies is shown. The fit is practically perfect. However, from Table 4 it is seen that the supposedly pure whites give some yellow anthers, which may be attributed to accidental cross-pollination or else might be accounted for by modifying genes. There is some excess of homozygotes to heterozygotes. Still, when plants Nos. 7 and 10 are eliminated owing to the fact that No. 7 had a yellow-anthered parent and No. 10 was probably a natural hybrid, the ratio of homozygotes to heterozygotes is good. According to the hypothesis, there is another type of ratio, the 13 white : 3 yellow, that has not so far been discussed. In Tables 1 and 2, progenies 179–110 and 69–14 gave such a ratio. Both of these had white-anthered parents and gave a total of 273 white to 49 yellow. This is a fair approximation of a 13 : 3 ratio, there being a deviation of 11 between calculated and observed, and P exceeds the 1% point.

TABLE 4.—*Segregation of yellow and white anther color in two families, family 34 where one dominant factor for yellow is found and in family 84, a factor pair making white dominant.*

Plant No.	Anther color		Total	Ratio	
	Yellow	White		Yellow	White
Family 34, Color of Parents was Yellow					
5	14	7	21	3	1
6	50	14	64	3	1
8	25	15	40	3	1
9	20	0	20	Pure	—
12	60	17	77	3	1
14	12	4	16	3	1
15	51	21	72	3	1
20	26	14	40	3	1
22	16	0	16	Pure	—
27	69	0	69	Pure	—
31	49	24	73	3	1
32	30	3	33	Pure	—
34	108	35	143	3	1
Total 3:1 progenies	395	146	541	P = .20 to .30	
Family 84, Color of Parents was White					
1	0	154	154	—	Pure
2	3	10	13	1	3
5	10	33	43	1	3
6	12	135	147	—	Pure?
7	4	2	6*	?	—
8	7	69	76	—	Pure?
10	11	1	12	?	—
12	17	59	76	1	3
17	1	13	14	—	Pure?
18	5	17	22	1	3
19	4	56	60	—	Pure?
20	24	52	76	1	3
Total 1:3 progenies	59	171	230	—	—
Calculated 1 to 3	57.5	172.5	230	—	—

*Color of parent yellow.

The interrelations of the three factors P, B, and I as given here and as shown by the several different types of ratios in three generations should not be an unusual example in cotton. There are comparatively few interrelations reported in cotton, but on account of the large number of pairs of chromosomes in the New World cotton, and their relatively small size, such interrelations should be very common.

SUMMARY

Data are presented on anther color in cotton which seem to verify the hypothesis that there are two basic genes, P and B, for yellow and white anthers, with an additional gene, I, which when present inhibits either P or B when either is alone. The interrelations of these

three genes are shown by the several ratios of yellow to white, namely, 42 : 22, 3 : 1, 9 : 7, 13 : 3, 15 : 1, 1 : 3, and 3 : 13.

Such ratios should not be uncommon in cotton, owing to the large number of pairs of chromosomes found in the New World cottons.

LITERATURE CITED

1. BALLS, W. L. The Cotton Plant in Egypt. Studies in Physiology and Genetics. London: Macmillan's Science Monographs. 1912.
2. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1932.
3. HARLAND, S. C. The genetics of cotton, II. The inheritance of pollen color in New World cottons. Jour. Gen., 20: 387–399. 1929.
4. ———. The genetics of Gossypium. Bibliographia Genetica, IX. 1932.
5. KEARNEY, T. H. Segregation and correlation of characters in an Upland-Egyptian cotton hybrid. U. S. D. A. Bul. 1164. 1923.
6. MCLENDON, C. A. Mendelian inheritance in cotton hybrids. Ga. Exp. Sta. Bul. 89: 141–228. 1912.

A 25-YEAR FIELD COMPARISON OF HIGH MAGNESIUM AND HIGH CALCIUM LIMES[1]

T. E. ODLAND AND H. C. KNOBLAUCH[2]

THIS experiment was started at the Rhode Island Station in 1909 for the purpose of comparing the two kinds of lime, high magnesium and high calcium, in both the limestone and hydrate forms. Reports on various phases of this experiment have been published from time to time. It is the purpose of this paper to report the yields of crops obtained during the last 13-year period and to summarize briefly the results to date on soil reaction.

The interest in the relative merits of dolomitic and high calcium limes has been greatly stimulated in the last few years since it has been found that many soils along the Atlantic Coast are becoming deficient in magnesium (2, 5)[3].

A number of experiments have been reported where magnesium and calcium limes have been compared with respect to relative availability and neutralizing value. These comparisons have generally been for a much shorter period than those here reported. The Rhode Island experiment differs from most other long-time field comparisons in that all the forms are applied at a chemically equivalent neutralizing basis as determined by acid titration in the laboratory. The MgO content multiplied by 1.4 gives the theoretical CaO equivalent.

MacIntire (7) reached the conclusion that over a period of 4 years in lysimeter tests there was little difference between the availability of hydrated lime, limestone, and dolomite when the limestones were between 100 and 200 mesh in fineness and the soil was of good fixing capacity.

Metzger (9) in comparing hydrated lime, "plant lime" (a precipitated calcium carbonate), high calcium carbonate and dolomitic limestone in a laboratory study found their rate of reaction with the soil was in the order named. The author concludes, however, that it is doubtful whether any practical significance may be attributed to the differences in rates of reaction among the materials tested.

Lipman, *et al.* (6), in comparing magnesium and calcium limestones at three different rates of application over a 15-year period, found that the two forms of lime gave results that were quite similar. With the 4,000-pound application of magnesium limestone there were a few cases of crop injury. For the entire period there was a slight difference in favor of the magnesium limestone. There was some evidence to show that the magnesium limestone favored nitrogen fixation somewhat more than the calcium limestone.

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[2]Agronomist and Assistant Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 221.

DESCRIPTION OF EXPERIMENT

The arrangement of plats and treatments in this experiment have been described in detail by Hartwell (4). It consists of five plats each 2/15 acre in area. Four of these plats have been limed as indicated (Table 1) and one plat (82) has been left unlimed. The liming materials have been applied at a rate to give the same CaO equivalent on each plat with the exception that the south half of plat 74 has received 50% extra. Lime has been applied at six different times during the course of the experiment, namely, in 1909, 1914, 1916, 1921, 1924, and 1925. The total amount applied is approximately equal to 15 tons of limestone per acre. At the present time all limed plats show approximately a neutral reaction (Table 2).

Hartwell (4), in reporting the experiment in 1921, came to the conclusion that practically the same results may be expected with these different forms of lime provided the limestones are fine enough to pass through an 80-mesh screen and all forms are applied at the same neutralizing equivalent rate.

TABLE 1.—*Lime materials applied in pounds per acre to plats over a 25-year period on liming experiment.*

Plat No.	Kind of lime	Total pounds over 25-year period		
		CaO content	MgO content	CaO equivalent
74N.....	Calcium hydrate	13,918	874	15,142
76......	Magnesium limestone	7,887	5,396	15,441
78.......	Calcium limestone	14,448	596	15,282
80.......	Magnesium hydrate	7,699	5,453	15,333
82.......	None	0	0	0

TABLE 2.—*Soil reaction and lime requirement of plats in liming experiment.**

Plat No.	Kind of lime	Year									
		1921		1924		1928		1932		1934	
		pH	L.R.†	pH	L.R.	pH	L.R.	pH	L.R.	pH	L.R.
74N	Calcium hydrate	6.3	1,530	5.8	1,580	7.7	405	7.4	306	6.4	693
76...	Magnesium limestone	6.2	1,800	5.7	2,120	7.3	477	7.2	396	6.8	693
87...	Calcium limestone	6.4	1,530	5.7	1,670	7.5	396	7.4	324	6.7	450
80...	Magnesium hydrate	6.7	1,440	5.9	1,400	7.6	360	7.3	369	6.8	495
82...	None	4.9	3,690	4.5	4,400	4.6	3,708	5.0	3,501	4.3	3,717

*The authors are indebted to the Department of Chemistry for pH and lime requirement determinations. Lime requirement in pounds per acre according to modified Jones method.
†L.R. = Lime requirement.

Mather (8), summarizing the results in 1922, found that crop yields had been approximately the same on all four limed plats. The effect on the soil reaction had been about the same. Burgess (1), in

reviewing these results up to 1924, concluded that the limestones were apparently a little less permanent in their effect on soil acidity than the hydrates. He also found evidence that the magnesium limestone plat had produced a little larger average yield than had the other plats.

The forms and analyses of the lime materials used prior to 1921 have been reported in Rhode Island Bulletin 186. The limestones used in 1921, 1924, and 1925 were more finely ground than those used previously. In 1921, 72% of the calcium limestone and 60% of the magnesium limestone passed through a 200-mesh screen. In 1924 and 1925 the percentages passing through a 200-mesh screen were 78 and 85, respectively, for the two limestones.

The kind of fertilizer used has varied from year to year depending upon the crop grown. For cultivated crops it has approximated 1,500 pounds per acre of a 4–8–8 and for hay crops about 1,000 pounds of a 2–10–10. The nitrogen has been supplied in a mixture of nitrate of soda and sulfate of ammonia, the phosphoric acid chiefly in double superphosphate, and the potash in sulfate of potash-magnesia. The latter has been used in order to guard against possible magnesium deficiency in available nutrients. The double superphosphate was used in order to reduce to a minimum the amount of calcium supplied in the fertilizer.

After the last lime application in 1925, a pronounced manganese deficiency developed on all four plats receiving lime. After the trouble had been diagnosed, manganese sulfate was applied on the west half of each plat while the east half was left without manganese for comparison. The yields here presented are based on the part receiving manganese. With a number of crops very striking results have been obtained by the use of manganese on these plats (3).

No definite rotation of crops has been followed. The general plan has been to grow two years of cultivated crops followed by two years of grass. The yields of different crops are presented on a percentage basis in Table 3. This method was chosen in order that the relative yields of the different crops might be more easily compared. The actual computed yield per acre is given for the plat taken as representative of 100%. In some years when a number of crops have been included the area devoted to each crop has been rather small and therefore the yields should not be over emphasized.

Since the south half of plat 74 has received more lime than the other plats only the north half of this plat has been used for comparison where there has been an apparent difference in yield between the two halves. Beets and cauliflower in 1925, also corn and beans in 1926, have been left out of this comparison due to very poor or otherwise abnormal yields in these two years. Other crops grown during these two years are included.

In order to get a figure to represent the relative yield of each plat over the period under consideration the percentage yields were averaged. In a similar way the average percentage yields for the previous period, 1910 to 1921, were also averaged and are presented for comparison.

As may be seen in the table the average percentage yields for the period 1922 to 1934 were 82, 90, 89, 89, and 51 for plats 74, 76, 78, 80, and 82, respectively. For the previous period they were 86, 92, 90, 91, and 58, respectively.

TABLE 3.—*Percentage yields of crops on liming experiment.*

Year	Crop	Unit	Yield taken as 100%	Plat No.				
				74	76	78	80	82
1922.....	Rape	Tons	25.92	96	80	97	100	75
	Vetch	Tons	6.75	83	88	100	81	77
	Onions	Bu.	332	71	100	70	57	15
	Pumpkins	Tons	9.80	83	100	86	97	81
	Buckwheat	Bu.	46.50	84	74	100	84	97
	Parsnips	Bu.	644	92	100	95	87	60
	Leek	Cwt.	292	91	91	100	89	0
1923.....	Hay	Tons	1.24	81	100	97	100	60
1924.....	Hay	Tons	3.68	100	88	90	73	56
1925.....	Spinach	Bu.	2,000	82	100	63	76	0
	Oats	Tons	4.07	91	82	66	80	100
	Cabbage	Barrels	347	88	85	86	100	23
	Peppers	Bu.	556	100	87	70	68	46
	Beans	Bu.	23.00	83	96	83	100	65
1926.....	Lettuce	Cwt.	289	92	100	99	81	10
	Onions	Bu.	717	70	100	66	80	1
	Mangels	Tons	37.95	75	91	100	81	11
1927.....	Hay (green)	Tons	13.42	87	84	100	99	69
1928.....	Hay (dry)	Tons	4.54	100	99	89	95	64
1929.....	Sweet corn	Lbs.	10,091	87	97	92	92	100
1930.....	Hay	Tons	2.64	71	89	93	100	36
1931.....	Spinach	Bu.	3,136	59	100	98	84	2
	Beets	Bu.	195	71	55	100	74	7
	Potatoes	Bu.	172	53	79	100	93	98
	Mangels	Tons	25.00	72	73	78	100	51
	Tomatoes	Bu.	690	42	83	87	96	100
1932.....	Potatoes	Bu.	447	87	100	97	97	97
	Spinach	Bu.	776	82	77	79	100	0
	Tomatoes	Bu.	737	82	85	94	100	90
1933.....	Hay	Tons	1.94	94	100	87	82	52
1934.....	Hay	Tons	2.95	94	99	90	100	40
Average per cent, 1922–1934............				82	90	89	89	51
Average per cent, 1910–1921............				86	92	90	91	58

In both of these periods the unlimed plat, 82, has averaged about 40% less in yield than the limed ones. Among the limed plats, 76, 78, and 80, have been about on a par, while 74 has been a little lower in

each period. Records over a 15-year period previous to 1909 when this experiment was started and during which time all these plats were treated uniformly showed that plat 74 was as productive at the beginning of the experiment as the other plats.

DISCUSSION

The results obtained in the comparison of liming materials have shown that when these different forms are applied in amounts to supply the same neutralizing equivalent their effects on the soil reaction as measured by pH determinations have been equal over a 25-year period. In other words the theoretical value, MgO having 1.4 times the neutralizing value of CaO on a weight basis, has been verified under field conditions over a comparatively long period of years.

These tests moreover show that these four liming materials have had practically equal lasting qualities in the soil. The yields of crops following the application of the lime have also indicated that as far as rapidity of action goes there has been but little difference between the hydrate and limestone forms when the latter have been finely ground.

The yields of crops over the entire period of years also indicate that in general there has been little difference in these materials on net results in crops produced. The possible exception is high calcium hydrate which has the lowest average yield.

SUMMARY AND CONCLUSIONS

High calcium lime in both the hydrate and carbonate forms has been compared in field tests over a 25-year period with the same forms of magnesium lime. The lime materials have been applied at the same calculated neutralizing equivalent per acre.

The liming materials have been added at six different times during the experiment. The amount added approximates the equivalent of 15 tons per acre of limestone. This has brought the plats to a neutral reaction.

Both general farm crops and market-garden crops have been included. The same fertilizing materials have been used on all plats. Magnesium was supplied in the fertilizer in order to eliminate this as a factor from a nutritional standpoint as far as possible.

Manganese deficiency became evident on a number of crops after the soil had reached a neutral reaction.

Applied on the basis of equal neutralizing value there has been no appreciable difference between the different forms of lime with respect to their effect upon the soil acidity as measured by the hydrogen-ion concentration.

The average yields of all crops over the entire period calculated on a percentage basis were practically the same for the two forms of limestone and magnesium hydrate. The plat receiving calcium hydrate has averaged about 8% less in yield over this period.

From the data it may be concluded that these four forms of lime will give approximately equal results over a period of years when applied on a chemically equivalent basis if magnesium is not a factor from the nutritional standpoint.

LITERATURE CITED

1. BURGESS, PAUL S. The effect on present soil reaction of long-continued applications of equivalent amounts of high-calcium and high-magnesium limes. Soil Science, 18: 169–172. 1924.
2. CHUCKA, JOS. A. Magnesium deficiency in Aroostook potato soils. Amer. Potato Jour., 11: 29–35. 1934.
3. GILBERT, BASIL E. Normal crops and the supply of available soil manganese. R. I. Agr. Exp. Sta. Bul. 246. 1934.
4. HARTWELL, BURT L. Liming with high-magnesium versus high-calcium limes. R. I. Agr. Exp. Sta. Bul. 186. 1921.
5. KNOBLAUCH, H. C., and ODLAND, T. E. A magnesium deficiency induced by previous fertilizer treatments. Jour. Amer. Soc. Agron., 26: 609–615. 1934.
6. LIPMAN, J. G., BLAIR, A. W., MCLEAN, H. C., and PRINCE, A. L. A comparison of magnesian and non-magnesian limestone in some 5-year rotations. Soil Science, 15: 307–328. 1923.
7. MACINTIRE, W. H., SANDERS, K. B., and SHAW, W. M. The availability of hydrated lime, limestone, and dolomite of two degrees of fineness with supplements of red clover hay, as measured by lysimeter leachings. Jour. Amer. Soc. Agron., 25: 285–297. 1933.
8. MATHER, WILLIAM. The effect of limes containing magnesium and calcium upon the chemical composition of the soil and upon plant behavior. Soil Science, 13: 337–354. 1922.
9. METZGER, W. H. The rates of reaction with acid soils of finely divided soil liming materials. Jour. Amer. Soc. Agron., 25: 377–383. 1933.

SIMPLE AND RAPID METHODS FOR ASCERTAINING THE EXISTING STRUCTURAL STABILITY OF SOIL AGGREGATES[1]

GEORGE JOHN BOUYOUCOS[2]

THE finer portion of the soil and especially the colloidal fraction tends to become dispersed, to take up much more water, and to swell under one set of conditions in nature. In this physical condition the soil is regarded to be structurally unstable. Under another set of conditions the soil tends to be flocculated, coagulated, cemented, contracted, and to absorb less water. In this physical condition the soil is considered as being structurally stable. The factors that tend to produce these unstable and stable structural conditions are many, but chief among them are chemical composition of the soil colloids, application of certain fertilizers, the presence of certain native salts, and leaching.

The problem now is to devise methods which are capable of ascertaining which soils have a stable and which an unstable aggregate structure, and to measure, on a comparative basis, the degree of instability. At present, there seem to be no methods for making such determination.

In measuring the ultimate structure of soils (1)[3], the effect of various chemical agents on the rate of slaking of soils (2), and the effect of salts on the moisture equivalent and on the concentration of the soil solution (3), it was strikingly evident that of all the chemical agents employed potassium chloride and sodium hydroxide or sodium silicate had the most outstanding influence on the structure of soils. The potassium chloride tended to cause the greatest volume contraction and the greatest decrease in moisture content, while the sodium hydroxide or sodium silicate tended to produce the greatest dispersion, swelling, and increase in water content. Somewhat similar observations have been made by other investigators who have studied the effects of salts or exchangeable cations on soils or soil colloids (5, 6, 7, 8, 9).

It was at once suggested that advantage might be taken of the striking effect that KCl has upon soils in causing them to contract and in decreasing their water-holding power, to ascertain which soils possess a stable and which an unstable aggregate structure, and to measure the range of instability. It was reasoned that soils that were dispersed either as a result of leaching, or as a result of the presence of some chemical agent, and therefore possessing an unstable aggregate structure, would coagulate, flocculate, contract, and their water-holding power decrease when treated with KCl solution. Contrariwise, soils that were already flocculated, contracted and consequently in a stable structural condition, either as a result of chemi-

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[3]Figures in parenthesis refer to "Literature Cited," p. 227.

cal composition or of the influence of some chemical agent, would not show any or much physical change under the KCl treatment.

It is the object of this paper, therefore, to present two simple methods and the results obtained by them for ascertaining the existing aggregate structural stability of soils.

METHODS AND PROCEDURE

The methods adopted and employed for ascertaining the existing structural stability of soils by means of the KCl effects are (a) the moisture equivalent and (b) the volume on settling. These two diverse methods tend to check and supplement each other. The moisture equivalent was determined by the suction method (4) which is simple and rapid. It consisted of filling 2 small Büchner funnels 5 cm in diameter and 2½ cm in depth with air-dry soil that had passed through a 2-mm sieve. Care was taken to compact the soil by tapping gently the lower end of the funnels against the table. The filled funnels were placed in empty beakers and then one beaker was filled to the top with distilled water and the second with normal KCl solution. The soils were allowed to soak for about 24 hours or less and their moisture equivalent determined.

The volume on settling was determined by filling two 50-cc cylinders to the 40 cc mark with distilled water and with normal KCl solution, respectively. To each cylinder was added 15 grams of air-dry soil of the same stock that was used in the moisture equivalent determinations. After the soil had soaked for about half an hour it was stirred gently with an iron rod. The soil was first gently loosened by gradually working the rod to the bottom of the cylinder and then it was stirred by moving the rod in a forward and backward circular motion 20 times. This was repeated for each soil two or three times at intervals of about half an hour. The soil was then allowed to stand and settle for 24 hours and its settled volume recorded.

This mode of stirring allowed the soil to slake into its natural ultimate structure (1), to settle in a normal way, and to afford an easy outlet for the air to escape. It appears to be distinctly preferable to the shaking method wherein the palm of the hand is placed on the mouth of the cylinder and the soil is vigorously shaken. This latter method possesses at least two distinct disadvantages. First, in the case of the heavy clays which are very sticky and swell, it is almost impossible to loosen their particles or aggregates from the column formed, by shaking. Second, when the soil is shaken, upon settling, the particles and aggregates divide themselves according to size, whereas this does not happen when the stirring is done with a rod as described above.

With practically every soil the settled volume would become constant within 24 hours. With most soils, and especially those treated with KCl, the volume would become constant in a few hours. The liquid column above the soil column would be clear.

All experiments were conducted at room temperature. Changes of temperature caused no errors in the results because the tests for any one soil were run at the same time.

EXPERIMENTAL RESULTS

In Tables 1, 2, and 3, are presented the experimental results obtained on the structural stability of soils as revealed by their settling volume and moisture equivalent when treated with KCl solution

and when using water as a check. For each soil is also given its clay content as determined by the hydrometer method. From the results obtained the soils examined may be divided into three general classes in respect to the existing structural stability of their aggregates.

TABLE 1.—*Soils with aggregates of stable structure.*

Soils and treatments	Moisture equivalent, %	Settled volume, cc	Clay content 0.005–000 mm, %
Bladen loam 0–8 inches:			24.0
Water	24.3	14.0	
KCl	24.2	14.0	
Cecil clay loam 1–8 inches:			33.0
Water	19.8	13.0	
KCl	19.7	13.0	
Colbert clay 0–6 inches:			56.5
Water	29.9	15.5	
KCl	29.9	15.5	
Colbert clay 18 inches:			73.0
Water	47.0	19.0	
KCl	47.0	19.0	
Hagerstown silty clay loam 6–12 inches:			80.0
Water	33.7	17.0	
KCl	33.6	17.0	
Decatur clay 30 inches:			54.0
Water	29.7	17.0	
KCl	29.7	17.0	
Davidson clay loam 0–5 inches:			
Water	27.2	15.0	
KCl	27.1	15.0	
Nipe clay:			41.0
Water	30.0	13.4	
KCl	29.8	13.3	
Clay loam:			54.0
Water	35.2	18.0	
KCl	35.3	18.0	
Miami silt loam, subsoil:			46.0
Water	15.1	21.3	
KCl	15.0	20.8	
Irredel loam 10–20 inches:			74.1
Water	36.1	18.0	
KCl	35.1	18.0	

Class 1 comprises soils with a stable structure, class 2 those with unstable structure, and class 3 soils with moderately unstable structure.

Table 1 contains class 1 soils which reveal a stable existing aggregate structure. In these soils the KCl treatment produces no change in their settling volume and moisture equivalent from the order ob-

tained with water treatment. It is probably significant to note that lateritic soils are in this class and that these soils contain a low silica : iron-alumina ratio.

TABLE 2.—*Soils with aggregates of unstable structure.*

Soils and treatments	Moisture equivalent, %	Settled volume, cc	Clay content 0.005–000 mm, %
McKenzie clay:			76.0
Water	70.2	26.0	
KCl	43.0	19.0	
Marengo clay:			96.0
Water	71.4	25.0	
KCl	54.3	19.5	
Ontonagon clay C:			72.5
Water	42.4	21.7	
KCl	37.9	18.6	
Alkali soil:			67.0
Water	39.7	17.0	
KCl	33.2	15.0	
Lake Charles, surface:			42.0
Water	34.2	17.9	
KCl	27.2	16.3	
Miles fine sandy loam, surface:			38.5
Water	24.8	14.8	
KCl	20.7	13.0	
Buchner silty clay loam, surface:			39.5
Water	34.6	18.2	
KCl	29.2	16.2	
Grundy silty loam, surface:			38.5
Water	34.4	16.0	
KCl	28.2	14.3	
Montsuma loam 0–22 inches:			37.0
Water	30.8	15.5	
KCl	26.5	14.2	
Stockton clay adobe, surface:			73.9
Water	46.9	19.1	
KCl	37.2	16.0	
Fargo clay 6 inches:			60.0
Water	43.8	19.6	
KCl	37.0	18.0	
Lufkin clay 10–16 inches:			90.0
Water	66.1	22.5	
KCl	59.0	20.2	

Table 2 represents class 2 soils which reveal an unstable existing aggregate structure. In these soils the KCl treatment tends to reduce markedly both the settling volume and the moisture equivalent.

Table 3 contains class 3 soils which show only a moderately unstable existing aggregate structure. In these soils the KCl treatment reduced the volume and moisture equivalent to only a very moderate degree.

The settled volume and moisture equivalent always ran parallel and agreed with one another in every soil tested. This agreement by two diverse methods lends greater confidence in the reliability of the results.

TABLE 3.—*Soils with aggregates of moderately unstable structure.*

Soils and treatments	Moisture equivalent, %	Settled volume, cc	Clay content 0.005–000 mm, %
Janesville silt loam, surface:			23.0
Water	25.2	14.8	
KCl	23.4	14.0	
Marion silt loam, surface:			27.0
Water	27.6	15.5	
KCl	24.3	15.1	
Clinton silt loam, surface:			31.0
Water	27.5	15.7	
KCl	25.2	15.3	
Yolo clay loam, surface:			51.0
Water	41.4	18.0	
KCl	39.4	17.0	
Susquehanna clay 24 inches:			57.0
Water	35.8	19.5	
KCl	34.6	18.0	

All the experimental data contained in Tables 1, 2, and 3 were obtained with a normal solution of KCl. Many trials were made using different concentrations of KCl. It was found that the maximum effect on the decrease in volume and water equivalent was reached at the concentration of about normal. As the concentration was decreased, both the volume and water content tended to increase, showing that concentration also exerts an effect upon them.

SUMMARY

Potassium chloride has a most pronounced effect in contracting the volume and decreasing the water-holding power of deflocculated soils.

These phenomena were utilized in studying the structural stability of soil aggregates by measuring their settled volume and moisture equivalent when treated with normal solution of KCl.

From the experimental results obtained, the soils examined group themselves into three classes in respect to their existing aggregate structural stability. Class 1 contains soils which reveal a stable existing aggregate structure. In these soils the KCl treatment produces no change in their settled volume and moisture equivalent, but they remain the same as with the water treatment.

Class 2 comprises soils which reveal an unstable existing aggregate structure. In these soils the KCl treatment tends to reduce markedly both the settled volume and moisture equivalent.

Class 3 represents soils which show only a moderately unstable existing aggregate structure. In these soils the KCl treatment reduces the volume and moisture equivalent to a varied but moderate degree.

Both the settled volume and moisture equivalent always ran parallel and agreed with one another in every soil. This fact indicates that both of these methods give reliable results.

LITERATURE CITED

1. BOUYOUCOS, G. J. The ultimate natural structure of soils. Soil Science, 28: 27–37. 1929.
2. ———. Texture and structure of soils as influenced by chemical agents. Jour. Amer. Soc. Agron., 19: 788–797. 1927.
3. ———. Further studies on the freezing point lowering of soils. Mich. Agr. Exp. Sta. Tech. Bul. 31. 1916.
4. ———. The suction method for determining the moisture equivalent of soils. In press. 1934.
5. BAVER, L. D. The effect of the amount and nature of exchangeable cations on the structure of colloidal clay. Mo. Agr. Exp. Sta. Res. Bul. 129. 1929.
6. ANDERSON, M. S. The influence of substituted cations on the properties of soil colloids. Jour. Agr. Res., 38: 565–584. 1929.
7. JOSEPH, A. F., and OAKLEY, M. B. The properties of heavy alkaline soils containing different exchangeable bases. Jour. Agr. Sci., 19: 121–131. 1929.
8. MATSON, S. The influence of the exchangeable bases on the colloidal behavior of soil material. Proc. First Intern. Soil Cong. 2: 185–198. 1927.
9. WINTERKORN, HANS, and BAVER, L. D. Sorption of liquids by soil colloids: I. Liquid Intake and Swelling by Soil Colloidal Material. Soil Science, 38: 291–298. 1934.

METHODS FOR DISTINGUISHING BETWEEN LEGUME BACTERIA AND THEIR MOST COMMON CONTAMINANT[1]

ALVIN W. HOFER[2]

A CERTAIN soil saprophyte which has commonly been confused with the legume bacteria and which was first described by Beijerinck and van Delden (1)[3] as *Bacillus radiobacter* is well known today as a frequent contaminant of legume inoculants. Löhnis (4) called the organism *Bacterium radiobacter*; but Bergey (2) has placed it in the genus *Achromobacter* because *Bacterium* is not recognized in this classification.

The transfer from *Bacillus* to *Bacterium* was certainly justified, as nearly all bacterial classifications at present reserve the former genus for spore-forming bacteria. To a writer who continues to recognize *Bacterium*, however, there is no reason for taking it out of this genus until such time as its characters are sufficiently well known to place it in some genus with other bacteria to which it seems to be related. For the purpose of this paper, therefore, it will be denoted *Bacterium radiobacter* (Beijerinck and van Delden) Löhnis.

The first suggestion as to practical methods for differentiation between *Bact. radiobacter* and the legume nodule bacteria (species of *Rhizobium*) was offered by Löhnis and Hansen (5). They found that potato slants and litmus milk were useful for this purpose. *Bact. radiobacter* produced a brown coloration of the medium, while *Rhizobium* did not. In the hands of other investigators, however, the coloration produced by certain strains of *Rhizobium* and the lack of coloration on the part of certain strains of *Bact. radiobacter* were sufficient to confuse the results in many cases so that soil bacteriologists are reluctant to use these media. Another medium, veal infusion, was proposed by Hofer and Baldwin (3) because it allowed *Bact. radiobacter* to grow well, while most of the legume bacteria did not.

The present investigation was begun with the purpose of comparing a number of media inoculated with strains of *Bact. radiobacter* procured from various laboratories throughout the world and with several species of *Rhizobium* which were obtained originally from the collection of the University of Wisconsin. The first media to be tested were Endo's medium, eosin-methylene-blue medium, and other indicator media. None of these proved suitable, but tests of veal infusion showed it to have value. Two other media were developed for the purpose, and the description of all three follows.

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[3]Figures in parenthesis refer to "Literature Cited," p. 230.

MEDIA USED

Veal broth.—Add to 1¼ pounds of lean ground veal 1,000 cc of distilled water and refrigerate over night. Strain through cheesecloth and make up to a liter. Add 10 grams of peptone and 5 grams of salt. Steam 45 minutes and filter through paper. Adjust to pH 7.8 with N/1 NaOH (10–15 cc). Steam 45 minutes and adjust to pH 7.8 or 8.0. Filter through paper, tube, and sterilize.

Moderately alkaline liquid medium.—Mannitol, 10 grams; K_2HPO_4, 0.5 gram; $MgSO_4$, 0.2 gram; NaCl, 0.1 gram; $CaCO_3$, 0.05 gram; Bacto yeast extract, 3.0 grams; distilled water, 1,000 cc; N/1 NaOH, 18 cc; and 1.6% thymol blue, 1 cc. The reaction immediately after sterilization is pH 10.0 or above.

Strongly alkaline liquid medium.—The composition of this medium is exactly the same as that of the alkaline liquid medium above, with the exception that 28 cc of N/1 NaOH are added to each liter instead of 18 cc. The reaction immediately after sterilization is pH 11.0 or above.

All cultures were incubated at 25°C. The veal infusion was allowed to remain in the incubator for 5 days, the moderately alkaline medium for 6 days, and the strongly alkaline medium for 12 days. All determinations were made in duplicate. Because of the similarity in the results obtained with the veal infusion and the moderately alkaline medium, they are reported together. Although these two media usually produced splendid results, they were not always successful in differentiating between *Bact. radiobacter* and *Rh. meliloti*, the alfalfa organism. Because of this fact, strains of the latter species were omitted from the tests.

RESULTS

In the case of the veal infusion, a total of 90 individual determinations was carried out upon cultures of the genus *Rhizobium* in three tests. Growth developed in only two of these determinations. In the same tests, 127 individual determinations were carried out upon 50 available cultures of *Bact. radiobacter*, all of which produced growth in every instance. When inoculated into the moderately alkaline medium, *Bact. radiobacter* in 282 individual determinations during six tests produced growth without exception. *Rhizobium* cultures used during these six tests totalled 138, but none of these produced growth.

Because these two media were not suitable for distinguishing between *Bact. radiobacter* and *Rh. meliloti*, the strongly alkaline medium was devised. Three tests of this medium included 147 inoculations of *Bact. radiobacter*; 45 of *Rh. meliloti*, and 63 of other cross-inoculation groups of *Rhizobium*. After incubation, it was found that every culture of *Bact. radiobacter* had developed, as shown by the turbidity of the medium. With *Rhizobium*, growth occurred only in two cultures, both of which were for the inoculation of alfalfa.

This is by far the best record obtained with any of the media tested, and for this reason, it is felt that the strongly alkaline medium holds promise as a means of differentiating between the bacteria named. The only objection seems to be the length of the incubation period, but even this is shorter than that of cultures inoculated into milk or potato which may require up to 4 weeks.

There are certain precautions, however, which must be followed in the use of this medium. One is that typical forms of the organisms should be used rather than atypical, "yellow", or dissociated forms.

Another is that less than the stated amount of sodium hydroxide, rather than more, is necessary, because the amounts used in these experiments are near the alkaline end of the range within which the cultures will grow. Furthermore, since marked changes in pH sometimes occur in the incubator or refrigerator and since these changes reduce the sharpness of the distinction between the two groups of bacteria, the medium should contain thymol blue to show when these reaction changes occur.

Because an incubation period of 12 days at 25°C was found most favorable for the strongly alkaline medium and one of 6 days for the moderately alkaline medium, it is suggested that this time and temperature be used. This allows development of those strains of *Bact. radiobacter* which do not grow so rapidly as the rest. Also, agar must be omitted, because *Rhizobium* cultures are more likely to grow in the solid medium.

In conclusion, this investigation suggests that new tests for differentiating between *Bact. radiobacter* and various species of *Rhizobium* will be more likely to consist of the imposition of severe growth conditions upon the bacteria than in the selection of one from the other by such means as are used to distinguish the members of the colon-typhoid group. It is possible that other unfavorable growth conditions can be set up which would inhibit *Rhizobium* while still allowing growth of the more hardy *Bact. radiobacter*.

SUMMARY

Tests of veal infusion and of a moderately alkaline medium showed these media to be accurate in distinguishing between *Bacterium radiobacter* and strains of *Rhizobium* other than *Rh. meliloti*. These media did not require so long a time as milk and potato and the reactions were more clear cut. However, since they did not distinguish between *Bact. radiobacter* and *Rh. meliloti*, a strongly alkaline medium (about pH 11.0) was prepared for the purpose. This required more time for incubation than the other media, but it proved to be much more reliable. Because it distinguished between *Bact. radiobacter* and the more common species of *Rhizobium* there was no necessity for making an exception of the alfalfa group.

LITERATURE CITED

1. BEIJERINCK, M. W., and VAN DELDEN, A. Ueber die Assimilation des freien Stickstoffs durch Bakterien. Centbl. Bakt. (etc.) Abt. II, 9: 3–43. 1902.
2. BERGEY, D. H. Manual of Determinative Bacteriology. Baltimore: Williams and Wilkins. Ed. 4. 1934.
3. HOFER, A. W., and BALDWIN, I. L. The growth of rhizobia upon rich nitrogenous media. Jour. Bact., 23: 65–66. 1932.
4. LÖHNIS, F. Beiträge zur Kenntnis der Stickstoffbakterien. Centbl. Bakt. (etc.) Abt. II, 14: 582–604; 713–723. 1905.
5. ————, and HANSEN, R. Nodule bacteria of leguminous plants. Jour. Agr Res., 20: 543–556. 1921.

INDIGENOUS SPECIES OF RHIZOBIUM IN THE ARNOT FOREST[1]

J. K. WILSON[2]

IT has been noted in recent years that black locust (*Robinia Pseudo-Acacia* L.) is gradually spreading over certain areas of New York State. An examination of the roots of both seedlings and large trees shows that they bear nodules. Whether the organism that produces these nodules is indigenous to the various soils or whether it is spread over the countryside by one or more agents such as dust particles carried by the wind, flowing water, or transfer by animals from a center of infection is uncertain. Also, one or more species of nodulated Trifolium can be found on nearly all cultivated land in New York State, and in a few locations certain species of Medicago and Vicia can be found growing indigenously. The successful growth of such plants depends largely on the presence of the homologous root nodule bacteria in the soil.

Areas that have never been cultivated and have been occupied continuously, and almost if not exclusively, by non-leguminous vegetation are excellent places from which to obtain samples for a study of the indigenous presence of certain species of Rhizobium. Such an area is found in the Arnot Forest.

The Arnot Forest was a tract of virgin timber until 1870 to 1885. Logging occurred during this period. Approximately one-half of the tract was burned over between 1885 and 1928. It came into the possession of Cornell University in 1928. It consists of 1,883 acres and is located in southeastern Schuyler County, 18 miles southwest of Ithaca, N. Y. The topography is that of a deeply dissected plateau, ranging in elevation from 1,170 to 1,900 feet above sea level.

The only indications that leguminous plants have grown on the soils in this area were a few alsike clover plants along one of the stream banks and a few hog peanut plants at one edge of the forest. It is doubtful whether species of Medicago or of Vicia ever grew in the forest area. Also, so far as can be ascertained, no locust trees ever grew on this tract of land. A careful survey shows a few locust trees at a distance of 1 to 2 miles on two sides of the forest. These apparently represent encroachments toward the forest area. Only a few acres have ever been cleared and cultivated. These facts, together with the observation that rather large quantities of organic matter as forest litter are deposited on the surface of the soil every year, make it a very attractive place from which to obtain samples of soil for a study of the indigenous presence of certain species of the root nodule bacteria.

SOILS USED

Since Cornell University received this forest land the major soil types have been located and mapped. This made it possible to obtain samples of soil from the

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication January 2, 1935.

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major soil types which have been tentatively correlated and thus to add materially to the permanent value of the findings. The soils have been weathered from weakly glaciated till and are strongly influenced by the local shales and sandstone.

The samples which were used in this study were taken from the surface 3½ to 4 inches of soil. A place was selected from which to obtain the samples which looked as though it had never been disturbed. After the plant debris was removed the soil was loosened by means of a stiff spatula and then placed in previously sterilized pint mason jars. Before the spatula was used again it was wetted with 95% alcohol and the alcohol burned off. Twenty-six of the samples came from areas that so far as could be determined have never been cultivated, while three of the samples came from areas that sometime or other may have been cultivated. These samples of soil were collected July 27, 1934, and were obtained from those soil types which are recorded in Table 1. They represent seven soil series. The accompanying topographical map (Fig. 1) shows the location in the forest from which each sample came.

METHODS

In order to determine the presence or absence of the root nodule bacteria in the collected samples of soil it was necessary to grow leguminous plants on the soil and at the same time avoid contamination. To do this and to obtain suitable conditions for nodulation, 1-liter erlenmeyer flasks were used. In each flask was placed 500 grams of a dry sandy soil as a medium in which to grow the plants. The flasks were plugged and sterilized. A 20-gram portion of the sample of soil from the forest was weighed on a piece of clean paper and was then poured into the flask after the plug was temporarily removed. The sample was then mixed with the sandy soil in the flask by shaking the flask. Subsequently the soil was seeded.

The samples were examined for four species of the root nodule bacteria. Seeds of black locust (*R. Pseudo-Acacia* L.) were covered with concentrated sulfuric acid for 5 hours. They were then thrown into a large volume of water and most of the acid washed off. After this they were immersed in a solution of calcium hypochlorite for 10 to 15 minutes. The agent was then drained off and the seed rinsed once or twice in distilled water and well drained. While the seeds were still wet with the hypochlorite solution they were distributed on the surface of the soil in the erlenmeyer flasks. As soon as the seeds on the surface of the soil appeared to have dried sufficiently so that the chlorine from the calcium hypochlorite had disappeared, the soil medium in the erlenmeyer flasks received enough water to make conditions suitable for bacterial growth and seed germination. The water contained 0.05% saccharose and 0.01% K_2HPO_4. Seeds of vetch and red clover were covered with the acid for about 30 minutes, washed, and then immersed in the calcium hypochlorite solution. Seeds of alfalfa were immersed in the hypochlorite solution only.

In order to hasten germination and to produce uniformly good seedlings so that nodulation would readily occur in case the homologous root nodule bacteria were present, the seeds on the surface of the soil in the flasks were covered with some of the sandy soil. This was accomplished by dribbling some of the sterile soil through a funnel into the flasks thus covering the exposed seeds. The plantlets were 22 days old when they were examined for nodules. During this growing period when it was judged necessary, sterile water was blown from a wash bottle into the flasks after temporarily removing the cotton plugs. This was done in order to maintain suitable conditions for plant growth. It was necessary only once.

RESULTS

It is evident from the data which are presented in Table 1 that there were no root nodule bacteria for alfalfa or for vetch in a 20-gram portion of any of the 29 samples of soil. Bacteria capable of nodula-

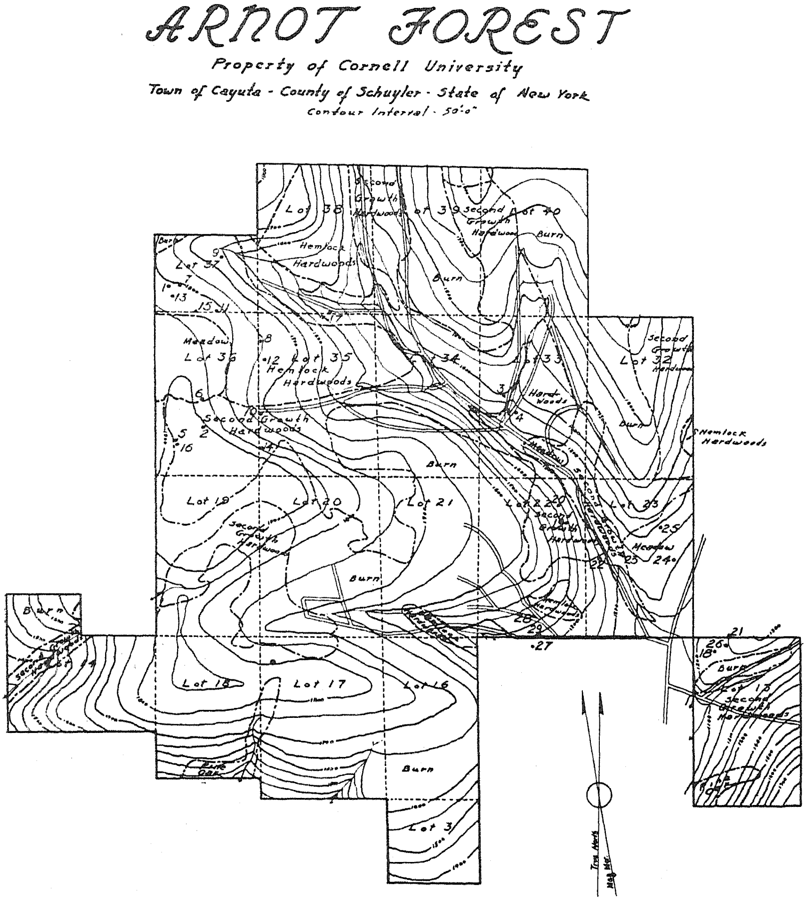

FIG. 1.—Map showing locations by serial numbers where samples were collected.

ting red clover were present in three soils. One of these was a Lordstown gravelly silt loam and the other two were Volusia soils. It is evident also that bacteria capable of nodulating locust seedlings were present in 5 of the 29 samples. They were present in four Volusia soils and in one Otisville gravelly silt loam. Homologous bacteria for red clover and locust were found together in two samples of the Volusia series.

To supplement the data presented in Table 1, flasks were seeded with the four legumes and inoculated with pure cultures of the homol-

TABLE 1.—*Recording the presence or absence of four species of Rhizobium in samples of soil from the Arnot Forest.*

Lot No.	Sample No.	Elevation, feet	Forest type*	Soil (tentative correlation)†	Litter‡	pH	Presence or absence of root nodule bacteria capable of producing nodules on §			
							Locust	Red clover	Alfalfa	Vetch
37	1	1,805	HH	Volusia s.l.	Grain mull	6.0	+	—	—	—
33	4	1,360	2nd	Volusia s.c.l.	Twin mull	5.4	—	—	—	—
35	10	1,730	2nd	Volusia s.l.	Twin mull	5.5	—	—	—	—
23	22	1,250	B	Volusia s.c.l.	Twin mull	5.5	—	—	—	—
23	25	1,275	M	Volusia s.l.	Meadow	4.9	—	—	—	—
38	17	1,480	2nd	Volusia s.c.l. (g.s.p.)	Twin mull	5.7	+	+	—	—
22	27	1,350	B	Volusia s.l. (g.s.p.)	Meadow	5.2	+	+	—	—
22	29	1,355	B	Volusia s.c.l. (g.s.p.)	Grain mull	5.3	+	—	—	—
36	2	1,850	HH	Lordstown g.s.l.	Detritus mull	4.7	—	—	—	—
36	5	1,920	2nd	Lordstown f.s.l.	Root duff	5.2	—	—	—	—
36	6	1,910	2nd	Lordstown g.s.l.	Root duff	5.4	—	+	—	—
35	8	1,820	HH	Lordstown g.s.l.	Root duff	5.0	—	—	—	—
37	11	1,900	HH	Lordstown g.s.l.	Root duff	4.7	—	—	—	—
35	14	1,810	2nd	Lordstown s.p.	Root duff	4.5	—	—	—	—
37	13	1,850	HH	Lordstown g.s.l.	Root duff	5.0	—	—	—	—
37	15	1,920	HH	Lordstown g.s.l.	Root duff	4.7	—	—	—	—
36	16	1,970	HH	Lordstown f.s.l.	Root duff	4.3	—	—	—	—
22	28	1,310	B	Lordstown g.s.l.	Root duff	4.0	—	—	—	—
33	3	1,390	H	Mardin g.s.l.	Root duff	4.8	—	—	—	—
37	7	1,800	HH	Mardin g.s.l.	Root duff	5.0	—	—	—	—
37	9	1,665	HH	Mardin g.s.l.	Root duff	5.0	—	—	—	—
35	12	1,805	HH	Mardin g.s.l.	Root duff	4.3	—	—	—	—
13	18	1,275	B	Otisville g.s.l.	Grain mull	5.8	+	—	—	—
13	26	1,280	B	Otisville g.s.l.	Twin mull	4.9	—	—	—	—
22	19	—	H	Bath g.s.l.	Root duff	5.0	—	—	—	—
22	20	—	H	Bath g.s.l.	Root duff	4.8	—	—	—	—
13	21	1,250	B	Otisville, eroded phase	Old field	4.8	—	—	—	—
23	23	1,245	M	Canfield g.s.l.	Meadow	4.7	—	—	—	—
23	24	1,250	M	Canfield g.s.l.	Meadow	4.8	—	—	—	—

*HH = hemlock hardwood; H = hardwood; 2nd = 2nd growth hardwood; B = burn; and M = meadow.
†s.l. = silt loam; s.c.l. = silty clay loam; g.s.l. = gravelly silt loam; f.s.l. = flaggy silt loam; s.p. = steep phase; and g.s.p. = grey surface phase.
‡Data furnished by C. H. Diebold, following classification of Romell (4).
§ + = Organisms present; — = organisms absent.

ogous root nodule bacteria. These were prepared to determine whether the conditions in the flasks were suitable for nodulation. Also, checks were provided to ascertain the reliability of the method. The results that were obtained from the supplementary tests indicated that the data were reliable and that they were suitable data from which conclusions may be drawn.

DISCUSSION

The 29 samples of soil from the Arnot Forest, representing 8 of the Volusia series, 10 of the Lordstown, 4 of the Mardin, and 3 each of the Otisville, Bath, and Canfield were examined for certain species of Rhizobia. The host plant of these species so far as could be ascertained has never grown in the forest area. This number of samples ought to be sufficient to show clearly whether Rhizobia species are indigenous in the Arnot Forest. It has been shown by Wilson (1)[3] that it is unnecessary in the case of the root nodule bacteria for Vicia and Pisium that these plants must grow on a soil before their homologous bacteria will establish themselves in the soil. If nutritional conditions are adequate and species of Rhizobia are naturally introduced they will survive as long as these conditions obtain, irrespective of whether the host has grown on the soil. If this view is tenable, then it is evident that Rhizobium for locust is indigenous in certain soil types in the Arnot Forest. This may be one reason why locust is gradually encroaching on certain areas in New York State, and may indicate that the homologous root nodule bacteria either precedes its host into new areas or that it is naturally present in certain soils. It should be pointed out, however, that the Rhizobium for locust was not indigenous in the Lordstown, the Canfield, the Mardin, or certain of the other soil series. This is taken to indicate that for this organism the nutritional conditions at the present time in these soil series are inadequate. These inadequacies either obtain for the Rhizobia of alfalfa and of vetch in all seven of the soil series and for the Rhizobium of red clover in 27 of the 29 samples of soil or these species of Rhizobia have never by chance come in contact with these soils. These unfavorable nutritional environments for the homologous bacteria species of Medicago and Vicia may explain in part why representatives of these two plant groups are not found indigenously in this forest area.

No evidence was obtained which might be regarded as furnishing a possible explanation for the presence of species of Rhi obium in one soil type and their absence from another. For this reason the data should not be taken to indicate, without further studies, that a soil of the Lordstown or Mardin series in another section of New York State would not support a certain species of Rhizobium because the organism was not found in the soil of these series in the Arnot Forest. After making a study of the relative numbers of three species of Rhizobia in Dunkirk soil, Wilson (2) concluded that no significance could be attached to the moisture content of the soil, to the season of the year when the samples were taken, or to the crop on the soil

[3]Figures in parenthesis refer to "Literature Cited," p. 236.

as bearing any relation to the ability of a soil to support certain species of this organism. It was suggested by Wilson (3) that other agents, such as the type of inorganic salts present in the soil solution and the quality of the organic matter in the soil, may be factors supporting Rhizobium in the absence of its symbiont.

It is evident from the data presented that the quantity of forest litter added to the soil from year to year is not effective in establishing and maintaining a population of certain species of Rhizobia of such magnitude that the organisms can be found in 20-gram portions of the soil. In addition the data are not extensive enough to show whether the forest type or the type of decaying litter as defined by Romell (4) bears a relation to these bacteria.

CONCLUSIONS

Soil samples were collected from seven soil series in the Arnot Forest. These were used as an inoculum for a medium in which leguminous plants were grown. The presence of nodules was the criterion of the presence in the soil of species of Rhizobium. It is concluded that the Rhizobium for black locust is indigenous in certain areas, that the Rhizobium for red clover is present in 2 of the 29 samples, and that the Rhizobia for alfalfa and for vetch were not present in any of the soil series examined.

LITERATURE CITED

1. WILSON, J. K. Legume bacteria population of the soil. Jour. Amer. Soc. Agron., 18: 911–919. 1926.
2. ———. Relative numbers of three species of Rhizobium in Dunkirk silty clay soil. Jour. Amer. Soc. Agron., 26: 745–748. 1934.
3. ———. Relative numbers of two species of Rhizobium in soils. Jour. Agr. Res., 43: 261–266. 1931.
4. ROMELL, L. G. Mull and duff as biotic euilibria. Soil Science, 34: 161–188. 1932.

COMPOSITION OF BLACK LOCUST LEAF MOLD AND LEAVES AND SOME OBSERVATIONS ON THE EFFECTS OF THE BLACK LOCUST[1]

A. F. GUSTAFSON[2]

DURING April 1934 the writer's attention was attracted to the organic material on the surface of the soil under a thick stand of black locusts (*Robinia pseudoacacia* L.). These locusts are located in the town of Bath, Mason County, in central Illinois. The soil is mapped as dune sand according to the Illinois soil survey, the soil map of Mason County having been made by a field party under the direct charge of the writer. It was during this work that the author became interested in the growing of the black locust on this dune sand of which 75,443 acres is found in Mason County. This acreage constitutes 21.37% of the area of the county.

This particular locust area was started by planting sprouts about 25 years ago for the purpose of controlling the blowing of the sand. During the intervening years the size of the planting has become enlarged greatly by natural means, mainly sprouting. Fires burn over this sand area all too frequently, the most recent fire having occurred in 1931. The heat from these fires is so intense as to kill most of the locust growth above ground, consequently the present growth consists of sprouts which have come up from the live roots since the latest fire.

The surface of the sand under the locusts was covered with the remains of the locust leaves and some small twigs which had accumulated during the past 3 years. In the absence of facilities for collecting samples, a board 12 inches square was placed on the surface of the soil. It was held down by standing on it and the organic matter cut off by running a knife around the edge of the board. The leaf material was then raked away from the board, the board removed, and the organic material collected from the square foot which the board had covered. The samples were taken to Ithaca, where dry matter, loss on ignition, and total nitrogen were determined. These data are given in Table 1.

A number of points are brought out by these data. First, it is little short of crime to permit the destruction by fire of 101 pounds of nitrogen and nearly 1¼ tons of organic matter to the acre, in addition to the killing of the above-ground locust growth.

While making the soil map, as well as since then, the writer observed Kentucky bluegrass (*Poa pratensis*) well established and making good growth under black locust trees even though this bluegrass does not grow on this sand away from groups of locust trees. The growth of bluegrass in association with the black locust appears fully explained by the above data; the locust leaves supplying nitrogen and other nutrients, holding moisture, and probably helping to hold

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, New York. Received for publication January 2, 1935.
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down the temperature of the sand during hot periods. Second, this organic matter in conjunction with the locust trees had completely stopped sand movement by the wind. Moveover, productive soil adjacent to active sand dunes is being destroyed by a covering of sand blown over it from the dunes. Even when the dunes "move on" sufficient covering of coarse sand is left to render cultivation of what was formerly good soil impracticable.

TABLE 1.—*Composition of black locust leaf material and quantity of it to the acre.*

	Samples		
	1	2	Average
Air-dry sample (including some underlying sand), grams	97	95	96
Moisture, %	5.69	6.15	5.92
Nitrogen (air-dry basis), %	1.260	1.152	1.206
Loss on ignition, %	25.83	25.77	25.8
Weight of material over an acre (including some sand), lbs			8,695
Nitrogen per acre in material (1.282%, average, dry basis), lbs			101.47
Loss on ignition per acre, lbs			2,243

This observation suggests the use of black-locust wind breaks or solid planting of locusts on sand dunes or light sandy loams for anchoring the sand in its present position. The use of conifers interplanted with locusts might be feasible, provided the growth of the locusts is controlled so they do not over-top the conifers and prevent their making the desired growth for wind-break purposes.

Chapman[3] has shown that the effect of black locust leaves blown over among such deciduous trees as catalpa, white ash, tulip poplar, black oak, and chestnut oak is to increase their growth materially both in height and in diameter immediately adjacent to the locusts as compared with distances of 12 to 72 feet away. The same relationship precisely was found in the nitrogen content of the soil, it being 0.196% among the locusts and 0.090% at a distance of 72 feet from the locusts. As Chapman points out this difference may appear to be small, but it is equivalent to 3,900 pounds of nitrogen to the acre among the locusts and to 1,800 pounds 72 feet away, a difference of 2,100 pounds to the acre—6 inches weighing 2,000,000 pounds.

Chapman gives the nitrogen content of elm and of a mixture of elm and locust leaves throughout the season. For October 12 the nitrogen content of the elm leaves was 2.06% and that of mixed elm-locust leaves 2.46%.

The writer collected leaves from black locust trees in Ithaca on the edge of the Cornell University Campus about October 9, 1934. Owing to the shorter growing season at Ithaca as compared with Ohio, however, the stages of maturity of the leaves from these two places are not strictly comparable. The nitrogen content of the locust leaves at Ithaca was 2.33% (dry basis), which is practically the same as that

[3]CHAPMAN, ARTHUR GLENN. Report of the fourteenth annual meeting of the American Soil Survey Association. Bul. 15: 39–41. 1934.

of red clover at full bloom. Red clover cut at approximately that stage at Ithaca contained 2.34% nitrogen[4] in the first cutting as an average of ten analyses covering a decade. During the same period the second cutting had on the average 2.75% nitrogen.

Ebermayer[5] reports beech and pine as producing 2,800 pounds of dry matter to the acre as leaves and needles and 3,000 pounds of beech leaves to the acre in France.

If the black locust produces approximately this quantity of leaves, they contain about 70 pounds of nitrogen to the acre, or on the basis of a ton of locust leaves, 46.6 pounds of nitrogen to the acre. This is an important contribution of nitrogen and organic matter to the soil.

This calculation is made purely for the purpose of calling the attention of workers to the possibility of using legume trees in plantations with non-legumes. Control of the legumes will be essential owing to their rapid growth. Over-topping of non-legume trees might be avoided if these are planted in narrow belts alternated with belts of locusts.

AGRONOMIC AFFAIRS

PLAN FOR ADMINISTERING THE ANNUAL CHILEAN NITRATE AWARD FOR RESEARCH ON THE RARER ELEMENTS IN AGRICULTURE

THE Chilean Nitrate Educational Bureau is providing the sum of five thousand dollars annually as an award for research on the value of the rarer elements in agriculture. The award will be sponsored by the American Society of Agronomy.

The plan for administering the award is as follows:

1. The award shall be known as the Chilean Nitrate Award for Research on the Rarer Elements in Agriculture.

2. The purpose of the award is to stimulate research with the rarer elements in relation to economic crop production.

3. Details of administering this award shall be in the hands of a committee of six, chosen from among the members of the American Society of Agronomy and known as the Committee on the Chilean Nitrate Award for Research on the Rarer Elements in Agriculture.

4. The committee administering this award shall be appointed by the President of the Society and shall consist of two members being appointed for 3 years, two for 2 years, and two for 1 year. Vacancies created by the automatic retirement of two members each year shall be filled by the President of the Society, each incumbent being appointed for a period of 3 years. Each incoming President of the Society shall designate the Chairman of the committee for the ensuing year.

5. Awards shall be made to individuals for outstanding research on the presence of the rarer elements in plants and their rôle in crop production and plant nutrition.

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[4]Unpublished data supplied by Dr. T. L. Lyon, Agronomy Department of the Cornell University Agricultural Experiment Station.

[5]EBERMAYER, ERNEST. Phys. Chem. der Pflanz., 1: 41–44.

6. The awards are to be used by the recipients in furthering research on the rarer elements or for professional advancement.

7. The amount of each award shall be determined by the committee in each individual case.

8. In making the awards the committee shall consider:
   (a) The work accomplished, as indicated by published and unpublished data.
   (b) The interest and activity of the worker in research.

9. Any research worker in the United States or Canada shall be eligible to receive recognition.

10. The announcements of awards shall be made each year at the annual meeting of the Society.

M. J. Funchess
C. F. Shaw
J. G. Lipman
Oswald Schreiner
H. H. Zimmerley
R. I. Throckmorton, *Chairman*

Committee on the Chilean Nitrate Award for Research on the Rarer Elements in Agriculture.

The committee requests that the Chairman be advised of all applicants and nominees for the award and that copies of all published reports of research and, when possible, manuscripts of unpublished results of research be sent to him. The names of all applicants and nominees and reports on their research should be sent to the Chairman by August 15, 1935.

A BIBLIOGRAPHY ON THE RARER ELEMENTS

The Chilean Nitrate Educational Bureau announces the publication of a bibliography containing some 1,800 references on the rarer elements assembled by Dr. L. G. Willis of the North Carolina Agricultural Experiment Station.

When ready, this bibliography will be distributed without cost to all who desire copies as long as the supply lasts. Those who wish to receive copies of the bibliography should notify the Chilean Nitrate Educational Bureau at 120 Broadway, New York City.

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OBSERVATIONS ON THE WHOLE WHEAT MEAL FERMENTATION TIME TEST[1]

E. G. BAYFIELD[2]

PLANT breeders desiring to undertake quality studies early in the development of new varieties are handicapped by having but small quantities of seed available. Such quality studies are particularly necessary to the originator of new wheats. Orthodox methods for testing such wheats require several pounds of seed if regular milling and baking studies are to be undertaken. Tests for evaluating the quality of new wheats before these several pounds of seed become available have long been needed. Great interest was aroused, therefore, when Pelshenke (15)[3] and Cutler and Worzella (8) published details of their methods for testing wheat quality using small amounts of whole wheat meal.

Since their original paper, Cutler (7) and Cutler and Worzella (9) have published further results obtained through the use of their test. Based upon these results, they (9) suggest a classification of wheats based upon the "time" as an index of quality. Wilson, Markley, and Bailey (20) found no significant correlation between the time test and protein content or loaf type when working with hard spring and hard winter wheats. They experienced considerable trouble in determining the end point of the test. Wilson and Markley (21) found a positive correlation with spring wheats ground on a Wiley mill between time of dough ball disintegration and loaf volume and baking strength score. They conclude that the test has possibilities.

Markley (13), in discussing the usefulness of the test, states (referring to Minnesota wheats), "You can tell extremes, but you cannot differentiate in the median group at all." Working with Michigan-grown soft wheats, Winter and Gustafson (22) found a fair positive correlation between the time test and loaf volume, and with expansion of dough, but not with protein content of flour. They used a modified method for determining "time," although their procedure was essentially the same as that outlined by Cutler and Worzella (8). Winter

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication January 7, 1935.
[2]Associate in Agronomy (Cereal Chemist).
[3]Figures in parenthesis refer to "Literature Cited," p. 249.

and Gustafson performed the tests at a temperature of 86° F (30° C) instead of 80° F (26.7° C) which was employed by Cutler and Worzella.

Up to the present time the author has not heard of anyone in this country working with the Pelshenke (17) procedure, which is apparently being used with success in Germany. Edel (10) reports favorably on its value after applying the test to over 2,000 samples. Pelshenke (16, 18, 19) has used his method in making wheat surveys of Germany for the 1932, 1933, and 1934 crops. However, Moh and Klemt (14) are somewhat critical of the method and advise against its introduction into Germany. Klemt (12) does not believe the "Schrotgärmethode" (the time test) a good substitute for the baking test. Results obtained by the author at the Ohio Station would indicate that Pelshenke's (17) procedure might well be tried out by wheat breeders in this country. Griffiths and Cayzer (11) have found the method promising when applied to Australian wheats. The essential difference between the Pelshenke and the Cutler-Worzella methods is the difference in size of dough balls used.

In the late summer of 1934 a number of samples of wheat too small in size to mill and bake came to the author for a quality rating. It was decided to run time tests upon them using the Cutler-Worzella procedure with the exception of a minor variation in temperature of the fermentation cabinet. Some of the varieties in the group were standard sorts. Results were so unexpectedly erratic that it seemed advisable to investigate the test and study some of the possible causes of these variations. At this time it is proposed to present some of these results as a preliminary report. This seems advisable in view of the widespread need for an adequate method of treating small plant breeding samples of wheat.

SOURCE OF MATERIAL AND METHODS

The samples employed in these studies were all grown in Ohio in 1933 and 1934 and consisted of both red and white winter wheats. The 1934 material is treated in Table 1. The 1933 crop samples were residues of a part of a much larger series studied in connection with the work of the Tri-State Soft Wheat Improvement Association program (2).

Analytical data have been obtained by approved methods (1). Baking data were obtained through the use of a modified formula of the American Association of Cereal Chemists (3). Viscosity data were obtained by the use of a constant weight of flour method (5).

GRINDING THE SAMPLE

Between 60 to 65 grams of clean, sound, dry wheat were ground on a Wiley mill using the 1-mm sieve. No specific details regarding the standardizing of this make of mill have been laid down by Cutler and Worzella beyond the use of the 1-mm sieve. Rather extensive grinding tests indicated considerable variation could be produced by changing the methods of handling the mill. As a result of these tests the grinding procedure finally used was to grind the above-mentioned amount of wheat for 4 minutes at a machine speed of 700 R. P. M. The knives must have a clearance of between 0.009 to 0.010 inch. With this method a small

amount of fine branny material does not pass through the sieve. It is mixed in with the ground material and used in the test. Grinding for longer periods so that all material passed through the sieve did not produce appreciable differences in time over a range in strength as found between the "weak" American Banner and the "strong" Michikof varieties.

After grinding a sample, the mill was cleaned by the use of a small brush followed by an air blast provided by a hand-operated automobile pump equipped with a suitable rubber tubing hose. Very little loss was experienced by this procedure (about 1 gram).

TIME TEST DETERMINATION

The first tests were made according to the specifications outlined by Cutler and Worzella (9) with the exception of using a temperature of 30° C (86° F) instead of 80° F. Pelshenke (17) used a temperature of 31° to 33° C. The cabinet temperature was electrically controlled and varied less than $\pm$ 0.3° C. Humidity was maintained between 77 and 92% by circulating air over towelling partially immersed in water. Normally the humidity was about 88%. A high humidity is desirable, as drying of the top of the doughballs influences the time of disintegration. The author was privileged to receive a demonstration in the making of doughballs from Professor G. H. Cutler while at Purdue University and thereby acquired an idea of the "feel" of the dough. This "feel" is of a consistency of a rather stiff dough and it was attempted to have all the doughballs of this consistency. Separate lots of meal were weighed individually for each doughball.

As will be shown later, the 10-gram doughballs, as specified by Cutler and Worzella, gave erratic results due to *some* samples sticking to the sides of the beaker. Thereafter only 5 grams of meal, as used by Pelshenke (17), were used. With these 5-gram doughballs only 2.75 cc of yeast solution (10 grams Fleischmann bakers' yeast in 100 cc distilled water) were used. The specified (8) 150-cc low form beakers (approximately 5.4 cm diameter) and 80 cc of water were used. Before using, the yeast solution was allowed to stand in the cabinet at 30° C for about 30 minutes. The "time" was determined by the interval found to exist between time of placing the doughball in the beaker and its disintegration. This latter occurred when the first detached piece of dough hit the beaker bottom. An extremely small piece falling was not counted as having any significance. The entire procedure is empirical and constant attention is required in the observing of the smallest details.

To ensure the elimination of the personal element it was found advisable to perform the tests in duplicate on two successive days and to take the average of three "times." If agreement was not obtained by running four doughballs a third pair was run on the third day's run and so on. If a very short "time" wheat was being run (30 minutes or less), agreement between checks had to be within 3 minutes. For the strongest red winter samples a maximum disagreement of not over 7 minutes was permitted without re-checking.

EXPERIMENTAL RESULTS AND DISCUSSION

In carrying out the tests in connection with standardizing the Wiley mill it was found that the personal element entered into the test very largely. The operations of stirring the meal and yeast solution together in the beaker with the stirring rod, duration and method of kneading of the dough in the palm of the hand, and finally, the time

and method of rolling the ball between the hands before immersing in water, all affected the time. Considerable effort was necessary before an assistant could duplicate results consistently with the author. In this respect the time test is as open to criticism as the baking test.

Finally, with these difficulties under control the series of wheat in Table 1 was run, using the 10-gram doughballs. The samples had been stored in the laboratory and had thoroughly dried out before being ground into meal. Observation of the tests indicated a definite difference between the behavior of the Trumbull and Fulhio red wheat samples from the rest which were of the weak white types. In the case of the former the doughballs became inflated, rose to the surface of the water, and then flattened out and adhered to the beaker on all sides. Fermentation gradually slackened with gas escaping through the upper surface of the mass. The depth of the mass became less and less. After this the dough was practically "dead," but did not break down due to the support received from the beaker walls. Finally, due no doubt to the action of proteolytic enzymes and the hydrolytic action of the distilled water upon the gluten, a part or all of the bottom of the fermented mass fell to the bottom of the beaker.

TABLE 1.—*Strength of wheat varieties using 10- and 5-gram doughballs, 1934 crop samples, Wood County, Ohio.*

	Trumbull*	Fulhio*	American Banner†	Gold Coin†	Honor†	Cornell 254A1–101–19†
Sample No.	2516	2517	2518	2519	2520	2521
Crude protein, %‡	13.3	12.7	12.8	11.5	11.5	12.0
Moisture in meal, %	8.1	8.5	8.0	8.6	8.2	8.5
Time test, using 10 grams meal:						
Replicate 1, minutes	**148**§	**85**	29	27	40	28
Replicate 2, minutes	**147**	**152**	30	27	39	28
Replicate 3, minutes	**147**	**139**	29	24	39	28
Replicate 4, minutes	**146**	**132**	29	24	38	29
No. replicates required	4	8	4	6	4	4
Av., 3 closest replicates, minutes	147	43||	29	27	39	28
Total range in time, minutes	**146–148**	39–**152**	29–30	24–29	38–40	28–29
Time test, using 5 grams meal:						
Replicate 1, minutes	57	63	33	30	45	33
Replicate 2, minutes	57	53	33	29	45	32
Replicate 3, minutes	57	56	32	31	46	33
Replicate 4, minutes	57	52	33	29	44	33
No. replicates required	4	4	4	4	4	4
Av., 3 closest replicates, minutes	57	54	33	29	45	33
Total range in time, minutes	—	52–63	32–33	29–31	44–46	32–33

*Soft red winter variety.
†Soft white winter variety.
‡Converted to 15% moisture basis.
§Bold face figures refer to samples adhering to sides of beaker.
||Final four replications were 45, 45, 40, and 39.

In the case of Fulhio some doughballs started to break up before becoming firmly attached to the beaker and irregular "times" resulted. With the white wheat samples all of the doughballs broke up before they became attached to the beaker. In these cases the gluten was exposed continually to the ever-increasing pressure of the gas formed by the yeast until disruption of the ball occurred. This phenomena only occurred during the initial stages of the stronger wheat doughballs which were prevented from complete breakdown by the support of the beaker walls. In the latter case an entirely different factor was operating and it seems as though the results between the red and white wheat samples are not comparable. In any empirical method every effort must be made to make conditions uniform, otherwise results are not strictly comparable.

The Cutler-Worzella (9) specifications call for a proportionate reduction in beaker size, amount of water, and yeast solution if the quantity of meal is reduced. Use of these instructions with a smaller sized doughball would therefore continue the above-mentioned error due to method.

To study the relative influence of beaker size and varying amounts of water, a number of tests were run which indicated conclusively that varying the size of the beaker produced large differences in time, whereas varying the amounts of water in the beaker produced relatively small differences.

The question now arose as to whether this ability to adhere to the beaker was a varietal characteristic. While this seemed an unlikely possibility, nevertheless a series consisting of 10 varieties grown at four different Ohio locations in 1933 was run by both the 10- and 5-gram doughball methods. These samples had previously been subjected to milling and various other laboratory tests and were selected so that the influence of varying strength in the different varieties could be noted. The resulting time data, together with the results of certain other tests, are presented in Table 2. In this table the varieties are arranged in order of decreasing loaf volume according to results obtained from growing the same varieties at some 46 locations in Ohio, Indiana, and Michigan during 1932 and 1933 (4). The four samples of each variety included are arranged in order of increasing crude protein content. Each variety, therefore, has a spread in strength. Study of the table indicates a number of interesting points, as follows:

1. Using 10-gram doughballs, it is seen that all varieties, except American Banner, stick to the beaker at the higher protein levels, while with one exception "sticking" is not an interfering factor in the lowest protein level. Sticking to the beaker therefore is not a varietal characteristic but occurs in any variety provided it has sufficient strength.

2. With 10-gram doughballs, more replicates were required in order to get satisfactory checks than with 5-gram doughballs. In the intermediate strengths in the various varieties where sticking was rather a haphazard occurrence, wide ranges in time occurred between duplicates run in any day.

TABLE 2.—*Data for 10 winter wheat varieties each grown at 10 locations in Ohio, 1933 crop year.*

Sample No.	Wheat protein %	Loaf volume (regular), cc	Loaf volume (bromate), cc	Viscosity (flour) °MacM*	Whole wheat meal time test: 10 grams meal, No. tests	10 grams meal, Range,† min.	10 grams meal, Av.,† min.	5 grams meal, No. tests	5 grams meal, Range, min.	5 grams meal, Av., min.
				Red Rock						
1944	8.8	535	530	72	4	39–53	50	4	58–66	63
2054	9.9	595	550	83	6	**48–154**	**154**	5	44–52	47
2044	10.2	565	532	92	8	**58–180**	**176**	4	53–65	54
1994	13.8	615	—	—	4	**202–208**	**203**	4	96–102	101
				Fulhio						
1943	9.0	532	530	78	4	38–48	47	4	53–56	54
2053	10.0	607	557	86	6	30–38	38	5	34–39	35
2043	11.2	585	595	125	4	40–45	43	4	46–50	49
1993	13.6	682	—	—	4	**180–186**	**184**	4	64–67	65
				Trumbull						
1941	9.0	540	505	76	4	44–49	48	4	55–58	57
2051	10.9	527	550	72	6	26–99	41	4	30–35	34
2041	11.2	585	557	110	7	**41–157**	53	6	44–60	46
1991	14.0	665	—	—	6	**161–184**	**171**	4	59–75	61
				Bald Rock						
1946	9.4	557	515	73	4	**63–140**	**138**	8	53–61	57
2056	10.0	575	562	72	6	**25–115**	39	4	39–42	42
2046	11.2	580	612	113	8	**46–151**	48	4	51–59	53
1996	13.9	650	—	—	6	**153–186**	**155**	4	63–73	65
				Gladden						
2060	8.1	530	475	47	6	32–40	39	4	33–36	35
1950	8.7	577	537	66	4	45–52	50	8	25–73	58
2050	11.0	605	612	112	8	50–63	56	3	51–56	54
2000	13.6	625	—	—	8	**54–196**	**179**	4	50–55	51
				Karkov						
2058	9.2	547	510	53	4	32–36	33	4	34–38	34
1948	9.8	575	557	81	4	44–47	47	4	44–48	45
2048	11.6	590	615	122	11	**45–158**	**108**	4	48–51	49
1998	14.3	627	—	—	8	**39–185**	**158**	4	51–56	52
				Michigan Amber						
1947	8.6	535	500	58	4	50–57	51	6	57–77	59
2057	9.4	550	517	71	6	**38–185**	44	4	41–45	42
2047	11.3	595	575	106	8	**51–181**	**173**	4	60–62	62
1997	14.0	640	—	—	4	**176–218**	**181**	10	68–85	79
				Fultz						
1949	9.1	552	520	80	4	45–47	46	4	49–64	50
2059	9.6	575	540	76	4	36–42	42	5	44–50	44
2049	11.1	570	577	124	7	43–51	48	6	46–57	48
1999	13.2	632	—	—	6	**168–201**	**172**	8	66–77	72
				Nabob						
1942	8.6	530	500	58	4	45–50	49	4	44–52	50
2052	9.2	567	512	44	6	34–120	37	4	31–39	38
2042	11.5	620	637	149	7	**54–174**	**167**	6	60–75	61
1992	12.8	605	—	—	4	**200–226**	**204**	4	74–78	77
				American Banner						
1945	9.0	520	510	48	4	34–36	35	6	34–50	37
2055	9.5	555	485	51	4	27–30	29	6	29–39	34
2045	10.8	550	590	79	4	30–35	34	4	38–41	40
1995	12.8	610	—	—	5	38–50	49	4	46–48	46

*Viscosity given in degrees MacMichael and obtained on 20-gram weight of 15% moisture flour.
†Bold face type refer to samples which stick to sides of beaker.

3. With either size of doughball there is a general tendency for increases in "time" with increasing protein content or loaf volume.

4. With the 5-gram doughballs or with the 10-gram size with no sticking, it will be observed that some other factor is interfering with this relationship between increasing time and strength. It will be seen that the protein content and baking strength in the 2051–60 series is higher than that of the 1941–50 series, although the time is less. Is the time in the latter series being unduly prolonged due to an insufficiency of sugar being available for the yeast to act upon?

5. With a given procedure, decreasing the size of dough ball gives relatively longer times provided no sticking occurs with the larger sized balls.

STRENGTH VS. QUALITY IN NEW WHEATS

The author prefers the use of the term *strength* rather than *quality* when referring to soft wheats and the measurements obtained by either the baking or time test. A strong baking flour or a long "time" wheat may be said to possess high quality for bread production, but such a strong wheat would not necessarily be of suitable quality for many of the purposes for which soft winter wheats are used. Thus, for example, the variety Michikof possesses a strong gluten, but for the manufacture of cake flour its quality is very poor. American Banner is a weak variety but is highly prized by many mills on account of its suitable quality for their purposes.

In measuring strength in wheat by any fermentation process such as by the time or baking tests, two principal factors must be considered, first, gas-retaining, and second, gas-producing abilities of the dough. Each factor is the resultant of several others, the most important of which may be expressed diagrammatically, as follows:

Wheat or Flour Strength

Gas-retention factors	Gas-production factors
1. Protein quantity	1. Sugar content of wheat or flour
2. Protein quality	2. Maltose producing ability (diastatic activity)
3. Activity of proteolytic enzymes	
4. Amount and composition of ash constituents	

In attempting to evaluate any new variety these various factors must be considered. In studying gluten or protein *quality* the amount of protein present in the sample necessarily must be considered. Furthermore, a sufficient supply of available sugar must be present in the dough, otherwise the gluten is not able to express its true strength due to an insufficiency of gas preventing the gluten being stretched to its point of rupture. Normally, in the baking test, sugar, malt, or some diastatically active material is added to the dough to ensure an adequate gas supply.

No action is taken along these lines in the time test, reliance being placed entirely upon the natural abilities of the meal itself plus the diastatic enzymes in the yeast. Recently, Coleman, Snider, and Dixon

(6) have shown that whole wheat meals vary widely in their diastatic powers. It has already been mentioned that the time of samples 1941–50 may have been influenced by a low gas production. Until the question of gas supply in the doughball is settled it must be considered as a possible source of error in the test. Seeing that diastatic activity is very considerably influenced by growing conditions, it appears as though it may eventually prove necessary to attempt to eliminate this possible variable in the time procedure.

USE OF "TIME" IN ELIMINATING UNDESIRABLE VARIETIES

The time test was developed by plant breeders primarily for the elimination of unsuitable varieties earlier in the breeding program than is possible when milling and baking tests are used. Much valuable material easily could be discarded if errors exist in the time test procedure. Table 3 shows that some varieties might easily be discarded due to the strength of the sample being exaggerated on account of the time being unduly prolonged by support being given the dough by the sides of the beaker.

TABLE 3.—*Variety strength rating according to time.*

Test	Series No.	Time in minutes*									
		Red Rock	Fulhio	Trumbull	Bald Rock	Gladden	Kharkov	Michigan Amber	Fultz	Nabob	American Banner
10-gm. 5-gm.	1941 to 1950	50 63	47 54	48 57	**138** 57	50 58	47 45	51 59	46 50	49 50	35 37
10-gm. 5-gm.	2051 to 2060	**154** 47	38 35	41 34	39 42	39 35	33 34	44 42	42 44	37 38	29 34
10-gm. 5-gm.	2041 to 2050	**176** 54	43 49	53 46	48 53	56 54	**108** 49	**173** 62	48 48	**167** 61	34 40
10-gm. 5-gm.	1991 to 2000	**203** 101	**184** 65	**171** 61	**155** 65	**179** 51	**158** 52	**181** 79	**172** 72	**204** 77	49 46

*Bold face type indicate samples which stuck to beaker.

Bald Rock in series 1941–50 is probably the worst example of this exaggerated strength as expressed by time when using the 10-gram doughballs. If sticking of the dough mass is avoided through the use of 5-gram doughballs, the wide spread in time between samples is reduced and this advantage claimed for the test is largely lost.

Examination of the 10-gram data also indicates that the varieties Nabob and Michigan Amber are relatively stronger than they actually are when considered in connection with their actual baking strength or their performance during the past 5 years of testing at the Ohio Experiment Station. These two varieties may possess low diastatic pow-

ers, seeing that even with the 5-gram doughballs they give "times" longer on the average than their known baking strengths would warrant.

SUMMARY

The whole wheat meal fermentation time test of Cutler and Worzella was applied to two series of soft winter wheats with unsatisfactory results due to the fact that uniform conditions do not hold over the range of strength found to occur in this class of wheats. With weak samples of wheat the dough mass does not stick to the sides of the beaker, whereas with stronger samples it does, with the result that strength differences as measured by "time" are exaggerated. "Sticking" of the samples in many, but not all cases, masked any differences caused by possible diastatic activity deficiencies.

The 5-gram doughball recommended by Pelshenke gives superior results to those obtained by the larger sized doughs. Even with these smaller doughballs, however, a disturbing influence is noticeable. It is thought that this may be due to diastatic differences in samples.

Closer agreement was obtained between viscosity results, loaf volumes, and protein contents than between the "time" data and the other determinations employed as comparative measures.

LITERATURE CITED

1. American Association of Cereal Chemists. Methods for the analysis of cereals and cereal products. Lancaster, Pa.: Lancaster Press. 1928.
2. Bayfield, E. G. The soft winter wheat improvement program for Ohio. Cer. Chem., 9 : 322–324. 1932.
3. ————. Soft winter wheat studies. II. Evaluating experimentally milled flours with the aid of viscosity, fermentation, and baking tests. Cer. Chem., 11 : 121–140. 1934.
4. ————. The effect of soil and climate upon wheat quality, 1930–1933. Dept. Agron., Ohio Agr. Exp. Sta. Mim. Rpt. 30, in 5th Ann. Rpt. of Tri-State Soft Wheat Improvement Assoc., Toledo, Nov. 1, 1934.
5. ————. The viscosity test. Cer. Chem., 11 : 637–647. 1934.
6. Coleman, D. A., Snider, S. R., and Dixon, H. B. The diastatic activity of whole wheat and some other cereal grains as determined by the Blish-Sandstedt method. Cer. Chem., 11 : 523–531. 1934.
7. Cutler, G. H. A whole wheat meal test for milling and baking quality. Assoc. Operative Millers, Oct. Bul., 455–458. 1932.
8. ————, and Worzella, W. W. A modification of the Saunder's test for measuring "quality" of wheats for different purposes. Jour. Amer. Soc. Agron., 23 : 1000–1009. 1931.
9. ————, ————. The wheat meal fermentation time test of "quality" in wheat as adapted for small plant breeding samples. Cer. Chem., 10 : 250–262. 1933.
10. Edel, P. Die Bestimmung der Kleberqualität bei Weizen mit der Schrotgärmethode. Unpaged reprint seen from Die Mühle, 5. 1934.
11. Griffiths, E. L., and Cayzer, L. S. The whole-meal fermentation time test. Agr. Gaz. N. S. Wales, 45 : 14–17. 1934.
12. Klemt, G. Die Schrotgärmethode zur Bestimmung der Backfähigkeit von Weizen. Zeitschr. f. d. ges. Getreide-und Mühlenwesen, 19 : 63–64. 1932.
13. Markley, M. C. Proc. 19th Ann. Meet. Amer. Assoc. Cer. Chem., page 14, Chicago, June 5–8, 1933.
14. Moh, K., and Klemt, G. Die Schrotgärmethode zur Bestimmung der Backfähigkeit von Weizen. Zeitschr. f. d. ges. Getreide-und Mühlenwesen, 19 : 25–29. 1932.
15. Pelshenke, P. Beiträge zur Bestimmung der Backfähigkeit von Weizen und Weizenmehlen. Archiv. für Pflanzenbau, 5 : 108–151. 1930.

16. ————. Über die Qualität der deutschen Weizenernte, 1932. Das Mühlenlaboratorium, Die Mühle, Leipzig, 40, No. 12, Oct. 6, 1932.
17. ————. A short method for the determination of gluten quality of wheat. Cer. Chem., 10 : 90–96. 1933.
18. ————. Über die Qualität der deutschen Weizenernte, 1933. Das Mühlenlaboratorium, Die Mühle, Leipzig, 3, No. 10, Oct. 5, 1933.
19. ————. Über die Qualität der deutschen Weizenernte, 1934. Das Mühlenlaboratorium, 9. 1934.
20. WILSON, H. K., MARKLEY, M. C., and BAILEY, C. H. The wheat meal fermentation test. Cer. Chem., 10 : 619–620. 1933.
21. ————, ————. The wheat-meal test for evaluating the qualities of small samples of wheat. Jour. Amer. Soc. Agron., 26 : 580–586. 1934.
22. WINTER, O. B., and GUSTAFSON, A. G. Some experiences with the wheat-meal fermentation time tests for evaluating soft wheats. Cer. Chem., 11 : 49–56. 1934.

SENSITIVITY OF THE POTATO PLANT TO SOIL AERATION[1]

JOHN BUSHNELL[2]

IN a fertilizer experiment at Wooster, started by Thorne[3] in 1894, potatoes have been grown in a 3-year rotation with wheat and clover. On the well-fertilized plats the wheat and clover have yielded well, but the potato yields have been below expectation.

The soil is mainly Wooster silt loam, characterized by excellent capillarity and a well-oxidized subsoil. For general agricultural purposes it is rated as one of the best soil types of eastern Ohio.

For many years the low yields of potatoes were attributed entirely to the prevalence of insects and diseases, but even when these were more and more successfully combated by spraying and the use of certified seed, the yields still failed to come up to expectation. By 1928 it was clear that either the rotation or the fertilizer treatments were not suited to potatoes.

On nearby fields a number of different rotations were then started. It was found that satisfactory yields could be obtained by heavy applications of manure or by large crops of green manures. Also, an extensive series of special tests was conducted within the fertilizer block itself on strips originally designed as roadways but which had been continuously cropped. These roadways were divided into 54 plats, each 10 by 15 feet. On some of these plats the less common fertilizer elements were added; on others new combinations of ordinary fertilizers were applied; on others the soil reaction was altered; and on still others the physical condition was changed by addition of sand or agricultural slag. Of all these special tests, the only ones giving yields distinctly higher than the ordinary fertilizers were the ones which received the applications of sand or of slag. Evidently, the problem was one of physical condition rather than of chemical relations in the soil.

RESULTS FROM SANDED PLATS

The initial tests with sand in 1929 and 1930 were applications about an inch thick spread on after plowing and disked into the top 3 inches of soil. The increases in yield were consistent but not large. The following seasons the sand was applied both before and after plowing and was thoroughly mixed through the plowed layer. The benefits were then more conspicuous (Table 1).

The problem seemed of sufficient importance to justify analyzing it a step further. To account for the benefits from the sand, three hypotheses seemed reasonable, as follows: First, moisture might have been conserved in the subsoil, due to rapid percolation of rain through the porous surface soil, followed by slower evaporation resulting from reduced capillarity; second, the porosity of the sanded soil might

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[3]The maintenance of soil fertility. Ohio Agr. Exp. Sta. Bul. 381. 1924.

have proved favorable for root extension; and, third, the increased aeration itself might have been of benefit.

TABLE 1.—*Increases in potato yields from adding sand to Wooster silt loam, single plats, 10 by 15 feet, yields in bushels per acre.*

Year	Sand applied per acre, cu. ft.	Yield of potatoes		Increase due to sanding, bu.
		Check, bu.	Sanded, bu.	
1929	3,600	145	177	32
1930	3,600	144	168	24
1931	7,200	259	322	63
1932	7,200	216	290	74

RESULTS FROM AERATION BY TILE LINES

For studying aeration as an independent factor, ventilating tile lines were laid in the surface soil of an adjacent field directly under potato rows. The lines were only 60 feet long and open at both ends. Presumably, these tile lines would aerate the soil near the potato roots without appreciably conserving moisture or altering the mechanical condition of the soil.

The tile were laid, after plowing, in ditches 10 inches deep, dug by hand. Two lines were laid with ordinary 4-inch clay drain tile and two with a perforated tile, each tile having 36 small holes along one side.[4] Three check rows were prepared by digging out the ditches and then refilling without tile. No method of forcing air through the tile lines was used. Changes in temperature and barometric pressure would presumably cause some gradual movement. At times, air movement could be detected by releasing a little smoke near the lower end of the lines.

After the tile were laid and the check rows prepared, Russet Rural potatoes were planted with a machine directly over the tile and at the same depth as in the check rows. There was only about an inch of soil between the top of the tile and the bottom of the seed pieces (Fig. 1).

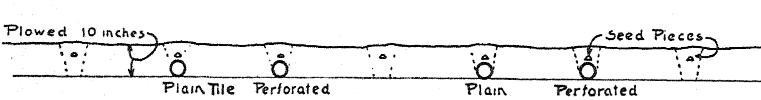

FIG. 1.—Diagram of location of tile lines. Dotted lines indicate narrow ditches dug by hand, three of which were refilled without tile; the others tiled as indicated.

The experiment was in a field which had been heavily manured in 1928 and in which soybeans had been plowed under in alternate years since. The soil, therefore, was in better condition for potatoes than any plats of the old fertilizer rotation. The experiment was conducted for two seasons, 1933 and 1934. Both seasons were very dry

[4]The perforated tile were furnished gratis by the Haviland Clay Works Company, Haviland, Ohio.

during the spring and summer but with favorable fall rains beginning about the middle of August. The rains were never heavy enough to pack the surface seriously or to cause the soil particles to coalesce in the plowed layer. Water ran out of the tile lines only twice in 1933 and five times in 1934.

The good condition of the soil and the favorable fall weather resulted in average yields from the check rows of over 300 bushels per acre both seasons, a very satisfactory yield in Ohio. The tiled rows, however, consistently outyielded the adjacent checks, and the perforated tile produced higher yields than the plain tile. The average total yields from the rows with perforated tile were over 400 bushels per acre, an increase of about 70 bushels per acre over the checks (Table 2).

TABLE 2.—*Effect of tile placed directly under potato rows, yield of 50-foot rows converted to bushels per acre.*

Row	Type of tile	Yield in 1933			Yield in 1934		
		Large*	Small	Total	Large*	Small	Total
1	None (check)	322.2	40.0	362.2	318.8	30.0	348.8
2	Plain	383.1	33.3	416.4	331.1	37.5	368.6
3	Perforated	404.8	48.4	453.2	367.5	26.5	394.0
4	None	288.4	41.9	330.3	268.0	28.3	296.3
5	Plain	341.3	37.4	378.7	324.5	33.8	358.3
6	Perforated	357.6	27.3	384.9	383.4	24.3	407.7
7	None	324.3	40.7	365.0	314.5	32.2	346.7
Averages							
Checks, no tile		311.6	40.9	352.5	300.4	30.2	330.6
Plain		362.2	35.4	397.6	327.8	35.7	363.5
Perforated		381.2	37.9	419.1	375.5	25.4	400.9

*"Large" tubers are those more than 1⅞ inches in diameter.

The tile were removed immediately after harvest and were found to be surrounded by a network of roots. Roots were distinctly more abundant around the tile than in the main body of the soil. This fact in itself might not be particularly significant when it is remembered that the roots originated directly above the tile; nevertheless, the fact that the roots thrived in the zone which was specially aerated supports the conclusion that the benefits from the tile were actually due to increased aeration. It should be noted, incidentally, that the increases in yield from the ventilating tile were of the same magnitude as those obtained in previous seasons from sanding.

CONCLUSION

The results, as a whole, lead to the conclusion that the potato plant is peculiarly sensitive to soil aeration, and that insufficient aeration may be frequently a limiting factor in potato yields on silt loam and heavier soil types.

PLANT BREEDING OPPORTUNITIES WITH PASTURE AND MEADOW PLANTS[1]

F. D. KEIM[2]

THE improvement of pasture and meadow plants by breeding is without doubt one of the most neglected fields in the agronomic research program. No one is to blame for this because there has always been a greater demand for research with cash crops such as corn, wheat, and other grains. When experiment stations were established most of the grain fields of the present time were covered with grasses and trees. Little agrostological research was needed because there was plenty of pasture and hay. Then, too, the many species used in pastures and meadows seem to have more or less overwhelmed investigators and they scarcely knew where to begin. Such factors as the small inflorescence, the non-individualistic growth habit, the long time involved in accomplishment, and the lack of specific knowledge concerning these small-seeded grasses and legumes have played their rôle in this neglect. It is always difficult to change the old regime. It is so easy to follow in the research groove of our forefathers.

Many worth-while fertilizer, tillage, and cultural experiments have been conducted with pasture and meadow plants, but the actual plant breeding activities have been limited.

The problems brought about by the necessity of regrassing lands as an aid in programs of erosion control, land utilization, grain reduction, etc., have created a distinct need for more knowledge concerning pasture and meadow crops. This need is a challenge to the agronomic investigators of the United States that can and will be met.

Some very excellent starts in agrostological research have been made in the United States, Canada, and especially in Europe. Special note should be made of this because failure to recognize it would be inaccurate and grossly unfair, but it will be the purpose of this paper to hold rather closely to the subject of breeding opportunities and not to discuss literature.

THE ADAPTATION OF GRASSES AND LEGUMES

While the common native and cultivated grasses and legumes are found rather generally over the country as a whole, careful observation shows that most of them have a rather distinct adaptation to particular habitats. This point is quite significant. It probably means that breeding operations must be limited to comparatively small areas. For instance, facts determined by Dr. Kirk in Canada with Alpha sweet clover may not hold true for the central corn belt of the United States. The strains of clover and grasses selected by Dr. Stapleton and his co-workers at Aberystwyth probably will not suit

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[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Published with approval of the Director as Paper No. 165 Journal Series, Nebraska Agricultural Experiment Station. Also presented at the annual meeting of the Society held in Washington, D. C., November 22, 1934. Received for publication January 7, 1935.

[2]Chairman, Dept. of Agronomy.

our plains conditions. In fact we already have fairly good evidence that this is the case. This means, of course, that these problems should be studied under soil and climatic conditions similar to those in which the plants are to be grown. If the most is to be gained by selection and hybridization, careful preliminary habitat studies will be necessary. Each agricultural experiment station, therefore, will have its own particular problems to solve, cooperating, of course, with each other and with the U. S. Department of Agriculture on methods as well as materials. In the writer's opinion it is not good policy to delimit the investigations of specific problems to too small a group of workers, as for example a single station. Whenever real initiative is shown it should be encouraged, even though there are some overlapping efforts in areas of similar growing conditions.

The adaptation of pasture and meadow plants may be illustrated with the following chart, which shows the tentative value of the cultivated grasses and legumes when grown under the various climatic conditions of Nebraska.

*Forage plants classified with respect to climatic adaptation to the various sections of Nebraska.**

Crop	Eastern Nebraska	Central Nebraska	Western Nebraska
	Grasses		
Brome	Good	Good to fair	Fair to poor
Crested wheat	Good to fair	Good to fair (or poor)	Fair to poor
Slender wheat	Good	Good to fair	Fair to poor
Orchard	Good	Good to fair (or poor	Fair to poor (or failure)
Meadow fescue	Good	Good to fair (or poor)	Fair to poor (or failure)
Red top	Good	Fair to poor (or failure)	Failure
Kentucky bluegrass	Good	Fair to poor (or failure	Failure
Timothy	Good to fair	Fair to poor (or failure	Failure
Sudan	Good	Good	Good
	Legumes		
Alfalfa	Good	Good to fair	Fair to poor
Red clover	Good to fair	Fair to poor (or failure)	Failure
White clover	Good to fair	Fair to poor (or failure)	Failure
Alsike clover	Good to fair	Fair to poor (or failure)	Failure
White or yellow-sweet clover	Good	Good to fair	Fair
Lespedeza	Good to fair	Fair to poor	Poor

*The above classification is based upon normal upland soil.

A similar type of adaptation could be shown for the native grasses and legumes. Any student that is well acquainted with the native vegetation of the Great Plains area knows that as one goes westward

from the Missouri River the long grasses, such as the blue stems, are left behind and one gradually passes into the typical short grass country which is covered with such grasses as grama and buffalo.

The intricate relationships that exist between the available soil moisture and soil types and the botanical structure of the native vegetation are striking. Prairie hay studies[3] made in north central Nebraska showed the natural plant communities divided into five general types, as follows: (1) Wet areas, *Spartina* (slough grass) type; (2) blue stem areas, *Andropogon furcatus* and *Sorghastrum nutans* (big bluestem and Indian grass) type; (3) drier areas of the bluestems, *Sorghastrum nutans* and *Andropogon scoparius* (Indian grass and little bluestem) type; (4) transitional areas between the bluestem type and the typical successional vegetation of the sandhills, including the *Stipa-Bouteloua* (needle grass and grama grass) climax vegetation; and (5) typical successional vegetation of the sandhills. Such special conditions need to be taken into consideration in a pasture and meadow improvement program.

WHAT ARE SOME OF THE PLANT-BREEDING OPPORTUNITIES?

CULTIVATED GRASSES AND LEGUMES

Brome grass (*Bromus inermus*) without much question is one of the outstanding grasses west of the Missouri River. The seed of brome grass, however, is extremely light and chaffy. The test weight per bushel ranges from only 12 to 20 pounds. If a strain with heavier seed could be developed, it could be seeded more easily with a drill, and this would enhance materially the chances of obtaining a stand. It would also greatly facilitate the threshing operation, which at present is almost an art in itself, as anyone can testify who has ever tried it. A strain of brome grass is also needed that has less of the so-called "sod binding" habit. Selection of strains suitable for pasture and others for hay would be desirable. The time of cutting brome grass for hay is very short. If this could be corrected and a strain selected that would cure and produce a better quality of hay and a greater yield, this crop would certainly have more value as hay.

Sweet clover (*Melilotus* sp.) is another plains and corn belt plant that has proved its worth and yet has some serious weaknesses. Strains are needed that will make maximum yields of fine, leafy hay instead of the usual coarse, stemmy material produced by ordinary varieties. Will it be possible to select or breed strains that do not have the bitter taste, which do not cause bloat, that are more resistant to certain diseases, that are more acid-tolerant, and that have a smaller number of hard seeds and are less subject to shattering? The harvesting of sweet clover seed from the common tall, branching types presents many difficulties. Can the plant breeder produce a plant that will give a maximum yield of seed, hay, and pasture, and yet will not be so difficult to harvest?

[3]KEIM, F. D., and FROLIK, A. L. Studies of prairie hay in north central Nebraska. Nebr. Agr. Res. Bul. 60. 1932.

FROLIK, A. L., and KEIM, F. D. Native vegetation in the prairie hay district of north central Nebraska. Ecol., 14 : 298–305. 1933.

Over the West, when fed alone, much difficulty is being experienced with sweet clover hay in the thinning of the blood of farm animals, which often results in serious bleeding at times of castration or dehorning. Sometimes animals actually bleed to death "in their own hides," states Dr. Van Es, animal pathologist at the Nebraska Agricultural Experiment Station. Can selections be made to do away with this trouble? Dr. Kirk, Dominion of Canada agrostologist, Dr. Brink at Wisconsin, and others have made some excellent beginnings. Studies on the subsoil moisture conditions prevailing in old alfalfa fields in the western part of the corn belt show rather clearly that uplands once in alfalfa are far less profitably cropped again to alfalfa. This fact makes sweet clover improvement all the more important.

Another unusually important temporary pasture and hay crop in the central part of the United States is sudan grass. A sudan grass is needed, however, that is somewhat more resistant to low temperature so that it can be planted earlier in the spring and the pasture season lengthened; one that ripens its seed more uniformly; and one in which there is no danger of prussic acid developing in large enough quantities to harm livestock. Possibly this last-named danger could be entirely eliminated. Strains of sudan grass selected chiefly from the standpoint of freedom from cane mixture are already being certified in a number of states. We need to go farther into the root of this trouble, however.

Lespedeza sp. could be used to better advantage if we had a desirable perennial, or if we had an annual that would make an earlier start in the spring and produce a larger tonnage per acre. With some improvement from the standpoint of hay quality and wider adaptation for both wet and dry conditions, Reed canary grass would be of much value on the low Scott and Fillmore types of soil areas over the plains. At the present time these areas are covered with weeds such as iron weeds, dock, and coreopsis.

Slender wheat, meadow fescue, and orchard grass need careful study. All of them have excellent possibilities and probably have been overlooked in western agriculture. The work of Sampson, Kirk, and others shows real possibilities especially with slender wheat grass.

More plant breeding work is being done at present with alfalfa than with any of the small-seeded grasses and legumes. It is needless to say that the accomplishments are gratifying. The results show what can be done when work is really started in earnest. There is little reason to believe that much the same improvement can be accomplished with the trifoliums and other cultivated legumes and grasses.

NATIVE GRASSES

The past summer has demonstrated rather clearly the value of the native grasses. Dried out and almost eaten out of the ground, these native grasses are beginning to show life, while the Kentucky bluegrass pastures of central and eastern Nebraska are at least 75% dead. The possibilities of selection within the various species of the native grasses were well demonstrated in some preliminary tests carried on at Nebraska this past summer. There was much evidence that there

is a great variation in plants of the same species. This variation was not confined to vegetative characters alone, but to the ability to produce good viable seed.

Blue stem (*Andropogon furcatus*) is probably one of the outstanding prairie hay grasses of the corn belt. It has at least three faults that might be corrected by plant breeding investigations. The seed is light and carries many bristles. The germination is poor. It is adapted to the more favorable soil and moisture conditions and therefore the distribution of this grass is somewhat limited. The grass if not cut before heading out makes a rather coarse, stemmy hay. It may be improved also in its stoloniferous characteristics so as to be of more value in erosion control. Much the same faults could be found with the other species of bluestem, such as *A. hallii*, *scoparius*, *saccharoides*, and *Sorghastrum nutans*.

Slough grass (*Spartina* sp.) and blue-joint grass (*Calamagrostis* sp.) are adapted to low, wet, poorly drained soils. There is an excellent chance that a finer-stemmed, softer-leafed slough grass might be selected so that the quality of hay would be improved and it would not need to be called "whip cord hay." Both of these grasses could be improved from a seed standpoint. *Calamagrostis* has a much finer leaf, but the seed is very difficult to procure. This might be greatly improved by removing it from the extremely sod-bound condition under which it usually grows.

Switch grass (*Panicum virgatum*) has one of the widest adaptations of any of the native grasses. It has excellent seeding qualities and the seed is not difficult to procure or handle. It produces a rather coarse hay, but this could no doubt be corrected by proper plant breeding methods.

The gramas and buffalo grass (*Bouteloua* sp. and *Bulbilis dactyloides*) over the drier plains area offer splendid possibilities. The side oat grama (*B. curtipendula*) is found almost everywhere. Its seed habits are such that it offers some excellent possibilities. Buffalo grass, being a dioecious plant with the pistillate flowers developing in the axils of the leaves of prostrate stems, causes seed production, and thus distribution, to be a greater problem. And yet, with some selection and proper cultural methods, it might be possible to harvest seed from this famous western grass. The work of Savage at Hays along the lines of vegetative propagation is especially noteworthy. At Lincoln, Nebr., we have found that a small 6-inch square of sod set every square yard fills in almost completely during one good, favorable growing season.

The *Agropyron* genus furnishes another group with some good possibilities. The fact that the hay feed seed division of the U. S. Dept. of Agriculture Bureau of Agricultural Economics has recognized western wheat grass (*Agropyron Smithii*) important enough to establish a set of hay grades for it indicates that it must have real value. Seed production of this grass is certainly one of its weak points. This has presented such a problem that it seldom can be found on the market. With careful selection and breeding, this deficiency can be corrected. Crested wheat grass, in spite of all the publicity it has received, is not as hardy for western Nebraska conditions as some of

the other species of *Agropyron*. Neither is it as hardy as *Bromus inermis*.

A few miscellaneous grasses adapted to special conditions should probably be mentioned here. Sand reed grass (*Calamovilfa*), blow-out grass (*Redfieldia*), and a number of drop-seed grasses (*Sporobolus* sp.) are especially adapted to extremely sandy lands. *Calamovilfa* has special stoloniferous qualities, spreading out in circles in the prairie almost like bindweed or quack grass. A few years ago in walking over a bad blow-out the writer pulled out, without breaking, a rhizome over 25 feet in length. It is extremely coarse and unpalatable both as pasture and hay. Here lies the opportunity for improvement. *Redfieldia* grows in the very loose sandy mouths of the blowouts and hence is called blowout grass. The inflorescence appears to be heavily loaded with seed. The *Sporobolus* species have very wide adaptations. *S. cryptandrus* is usually one of the first grasses to make its appearance on idle western lands that have been left to go back to grass. The writer has seen species of *Sporobolus* come up through 6 feet of blow sand. The seeds of many of these drop-seed grasses are large and smooth and should be rather easily harvested and planted.

HYBRIDIZATION

The possibility of combining the good quality of one small-seeded grass or legume with the good quality of another does not seem to be an unreasonable objective. These small-seeded plants undoubtedly present greater difficulties than the cereals, but the work at Aberystwyth, Ottawa, and in this country with timothy and alfalfa shows clearly that there are many possibilities ahead. Space does not permit a detailed discussion of hybridization. The fact that many of the grasses and legumes are cross-fertilized will present many difficulties. Real progress has been made with selfed lines of corn, and with the development of some special technic the same results can be accomplished with the pasture and meadow plants.

MISCELLANEOUS SUGGESTIONS

Three more suggestions will be offered. The first is along the line of cultural practice. Greenhouse facilities will be necessary to start selections and make the crosses. Special seeding operations, especially for the drier areas, should be taken into account. We summer plow and keep all weeds down for winter wheat production in dry-land agriculture. Why should we not do at least this much for these small-seeded grasses and legumes? There is the best of evidence at North Platte that brome grass stands are almost assured if this practice is carefully followed. This special seedbed preparation, with the use of a drill where possible, will do much to assist in making headway with plant-breeding operations.

The second suggestion has to do with man power. This work must be made one of the major divisions of the experiment station program and men must be placed in charge who have the proper agronomic and botanical training to do the job. This work must be a job and not one of the chores.

The third suggestion has to do with a more or less general condition. During the past few years soil erosion caused by both wind and water has called to our attention more than ever before that we have some serious soil problems to solve. Sodding this land with grasses and legumes and proper rotation seem to be the best remedy. In the past legumes have received much attention because of their fertilizing value. This has been good practice, but may we not have overlooked in part the importance of the soil-binding qualities of the fibrous-rooted grasses?

THE ADAPTATION OF CORN TO CLIMATE[1]

Donald F. Jones and Ellsworth Huntington[2]

RECENT investigations demand a revision of the prevalent idea that seed corn brought from a distance will not produce so abundantly as local varieties. It has been widely recognized that a change in latitude brings about a marked difference in vegetative growth and time of ripening because of the alteration in the relative length of day and night. The assumption has been that this change generally works adversely. It has also been assumed that a change in longitude, since it does not alter the length of the period of daylight, produces little effect except when it means a change to deficient summer rain. Nevertheless, the prevalent opinion throughout the principal corn-growing states has been that when seed is planted at distances of more than a few hundred miles east or west of where it was grown it will not do so well as varieties which have long been grown locally.

This widely held idea seems at first sight to be supported by practical experience. Seed from the North Atlantic states will not produce as much grain or forage in Ohio or Ontario as the best native sorts. Ohio and Ontario seed, in turn, usually does not give as good performance as the home-grown sorts in Illinois or Wisconsin. Local varieties from these latter sources, in turn, usually fail in Kansas, Nebraska, and the Dakotas, unless the season there is unusually favorable, as one of the writers well knows from his own sad personal experience in Kansas. Examples of this kind could easily be multiplied.

Other lines of evidence give partial support to the prevalent idea, but introduce elements of doubt. Recent experience in testing hybrid types of sweet corn in Connecticut furnishes an example. These hybrids have been developed from inbred strains of varieties that originated many years ago in southern New England, or nearby regions, and have always been grown there. In this section these varieties produce remarkably fine yields of well-formed, attractive ears. The best of the crosses derived from them are even more productive and attractive in ear formation. When seed of these new hybrids is sent to Maryland, Ohio, or Michigan, the reports are seldom favorable. Occasionally some types do fairly well, but not enough better than local varieties to justify extensive use. Invariably the reports from Illinois, Missouri, and Kansas indicate almost complete failure every year. It is hopeless to try to grow sweet corn from New England in those sections. The leaves begin to roll early in the season even when the soil is well supplied with moisture.

On the other hand, when the new hybrids are tested in certain other places, they do well. From central New England, New York, and some parts of Pennsylvania the reports are often favorable. Some Connecticut hybrid sweet corns have been grown for canning for

[1]Contribution from the Department of Genetics, Connecticut Agricultural Experiment Station and Yale University, New Haven, Conn. Received for publication February 1, 1935.

[2]Geneticist and Geographer, respectively.

many years in central New York with satisfactory results. Where they are not too late in maturing they usually do well in Massachusetts, southern Vermont, New Hampshire, and Maine. Somewhat to our surprise, many enthusiastic reports have also been received from northern Nevada, southern Idaho, and eastern Washington. There yields on some of our hybrid sweet corn have surpassed the production here.

The idea that corn seed from a distance does not grow well in new regions is rendered still more doubtful by other experiments. In Connecticut nearly all varieties of sweet corn that have been developed farther west and south grow remarkably well. Varieties from as far away as Florida and California have given good yields. Some of the newer sorts surpass the best local types in yield. Moreover, it is a regular practice in New England to grow ensilage corn from seed produced in many far distant regions. Much seed for this purpose is brought in from Iowa and Nebraska, partly on account of the low cost. Nearly all of this produces well-filled ears, and these often ripen sufficiently for husking. Curiously enough, the maximum yields of dry matter are produced from varieties native to Virginia and the Carolinas. Varieties such as Cocke's Prolific, Pamunkey, Shenandoah, and Golden Beauty, which seldom grow more than 9 or 10 feet tall in their native environment, regularly grow from 12 to 14 feet in southern Connecticut. In the majority of years the grain on these plants reaches the hard dough stage and in some years the ears can be husked and shelled. Yields of 50 bushels and more of dry shelled grain are common. Even when ears are not formed the production of dry matter is significantly more than from the largest Pennsylvania and Maryland varieties and much more than from the best local sorts.

It was formerly thought, without good evidence, that the dry matter in these late-maturing varieties was not equal in feeding value to the dry matter from more mature corn with a larger proportion of grain. White and Johnson (1)[3] and others at the Storrs, Conn., Experiment Station have shown that this is a serious error. Jones, Slate, and Brown (2) have tested the yield of corn from different parts of the country for 7 years at Mount Carmel, in southern Connecticut, and at Storrs, in the north central part of the state. Thus, the tests were carried out in two different biological zones (Upper Austral and Transitional) and on two distinctly different types of soil.

The varieties thus tested are grouped in Table 1 according to their place of usual cultivation. The figures there given show bushels of dry shelled grain expressed as percentages of the yield of the standard variety grown for comparison each year. This form of comparison is necessary because all varieties were not grown every year. The varieties are placed in four groups, *viz.*, Connecticut; New York and Massachusetts; Pennsylvania, Delaware, Ohio, Wisconsin, and Illinois; and the highest yielding Connecticut varieties. For the most part the varieties from outside Connecticut either originated in the

[3]Figures in parenthesis refer to "Literature Cited," p. 270.

states named or had been grown there long enough to be considered well adapted to their locality. Many Connecticut varieties had been grown here for more than 50 years. Some were more recent introductions from other states. Such high yields in Connecticut from seed grown at a distance are especially significant because the average yield of all local varieties of corn per acre is larger in Connecticut than in any other state.

TABLE 1.—*Relative yield of grain from dent varieties of corn from different sources in percentage of the standard variety grown in comparison each year.*

No.	Source	Mount Carmel, Conn.		Storrs, Conn.	
		Number of varieties	Yield %	Number of varieties	Yield %
1.....	Conn.	51	105.5	49	102.0
2.....	New York and Massachusetts	8	110.5	7	100.0
3.....	Penn., Del., Ohio, Wis., Ill..................	5	122.7	6	120.0
4.....	Highest yielding Conn.	5	128.1	6	122.3

It will be seen from Table 1 that on an average the seed from states adjoining Connecticut yields about the same amount of grain as local varieties, both at Mount Carmel and at Storrs. Seed from more distant regions is significantly more productive than the average of all local varieties at both places. This is due in part, possibly, to the fact that these distant varieties are adapted to a longer growing season. Many local varieties may mature too early to make the best use of our seasons. Other factors may be involved. Collins (3) has shown that there is a definite stimulus to increased production following a change in environment. By selecting an equal number of the highest yielding local varieties out of the large number grown, an obviously unfair comparison, we can make a little better showing for Connecticut-bred corn. The differences are not significant, and it cannot be said that locally grown varieties will produce more grain in these two different sections of Connecticut than varieties brought in from a thousand miles away. All that can be claimed is that local varieties will mature a better quality of grain, especially in unfavorable and short growing seasons.

Relatively little corn is grown for grain in New England. The bulk of the production is for ensilage. For this purpose the total yield in pounds of dry matter should be the chief consideration. Other important factors are involved which need not be discussed here. Dry matter determinations for the entire plant were made for the larger varieties included in the above tabulation and these are averaged for local and distant sources of seed. Again the yields are expressed in percentage of the standard variety grown each year. The results are given in Table 2.

Varieties from Connecticut, Massachusetts, and New York are placed in one group and all other varieties in another group. The local varieties are mostly adapted strains of Leaming, Reid's Yellow

Dent, White Cap Yellow Dent, and others with similar growing seasons. The distant varieties are as follows: From Pennsylvania, Lancaster Sure Crop, West Branch Sweepstakes, Clarage, and similar varieties; from Ohio and Illinois, Leaming and Funk's 90 Day; and from Delaware and Virginia, Eureka, Mastodon, Golden Beauty, and similar sorts.

TABLE 2.—*Relative yield of dry matter from ensilage varieties of corn from different sources in percentage of the standard variety grown in comparison each year.*

Source	Mount Carmel, Conn.		Storrs, Conn.	
	Number of varieties	Yield %	Number of varieties	Yield %
Conn., Mass., N. Y.	39	67.1	50	80.1
All others	7	85.4	10	84.8

In southern Connecticut the production of dry matter by the distant varieties is distinctly more than from the local varieties, while in the north central part of the state the production by the two types is about the same. From this trial and from feeding tests conducted at Storrs, the value of the larger and later southern varieties was realized. Consequently, a large number of varieties from the south and west were collected for a preliminary trial. From these a smaller number of varieties that seemed best suited to Connecticut were selected and grown for 4 years in comparison with the highest yielding local variety at Mount Carmel. Each variety was replicated five times and compared with the adjoining check rows on each side. The production stated as tons of water-free dry matter per acre is given in Table 3. (See Fig. 1.)

TABLE 3.—*Actual yield of dry matter per acre from ensilage varieties of corn from different sources grown at Mount Carmel, Conn.*

No.	Source	Number of varieties	Yield of dry matter, tons
1	Conn.	1	3.5
2	Penn.	3	3.4
3	Ohio, Ill.	4	3.6
4	Ga., La., Texas	3	3.9
5	Va., Carolinas	7	4.2

The Connecticut variety used for comparison was Burr-Leaming, a hybrid type developed partly from Illinois and partly from local Connecticut varieties, all grown here for about 20 years and well adapted to local conditions. It had about the same time of maturity as the Pennsylvania varieties used in this trial, which were again Lancaster Sure Crop, West Branch Sweepstakes, and Clarage. It regularly produced more grain than these varieties, but did not appreciably excel them in total dry matter, as shown in Table 3. The Ohio and Illinois varieties were various strains of Leaming and Funk's

FIG. 1.—Ensilage trials at Mount Carmel, Conn., in 1934. Varieties from Virginia and the Carolinas in the foreground. Photograph taken August 29.

90 Day. These yielded about the same as the Connecticut and Pennsylvania varieties. The Georgia, Louisiana, and Texas varieties were Yellow Creole, Hasting's Prolific, and Tuxpan. These were the latest in maturity and yielded somewhat more than the first three groups, but not as much as the fifth. Virginia and the Carolinas were represented by the varieties known as Cocke's Prolific, Pamunkey, Eureka, Golden Beauty, Virginia Pride, Blue Mountain, and Shenandoah. These produced 4.2 tons of dry matter per acre, about 8% more than the next highest group and 20% more than the standard Connecticut variety.

The evidence presented thus far in this article indicates that when seed corn is carried from one location to another the yield sometimes increases and sometimes decreases. Seed from Connecticut when planted elsewhere appears to be less productive than in its own locality except in certain northern areas. On the other hand, when seed is brought from practically any other part of the country to Connecticut the yield of both grain and vegetative matter appears to increase notably. The mere fact of a change of environment, regardless of the type of change, cannot explain these contradictory findings. The fact that Connecticut has the highest yield of corn among the states of the Union must also be considered. Connecticut produced 46 bushels per acre as a 20-year (1910–1929) average in contrast to 45 bushels in Massachusetts, which stands next, 42 in Pennsylvania, and 38 in Iowa, which is popularly supposed to be the best corn state. Corn seldom leaves the farm in New England and for that reason may not be so accurately estimated as in some of the other states. This is equally true for many other states and a large part of the crop in all states. Moreover, the average yields gradate so evenly from place to place that they seem to be reasonably reliable.

The high yield of corn in southern New England has usually been attributed to the small size of the fields. This is supposed to have led to careful cultivation together with more adequate fertilization. The average corn field in Connecticut not only has poorer soil than the average field in a state like Iowa, but it is not cultivated any better, if as well, and as a rule does not receive much more fertilization than many middle Atlantic states where the rainfall is equally heavy. In the middle western states the soil is so well supplied with plant food that there is little response to added elements even in years of abundant rainfall. In Connecticut, corn for grain is not always raised on the best soil. Farmers give their most productive land and most of their care and fertilizer to fields devoted to more profitable crops like sweet corn, potatoes, and other vegetables. Therefore, neither soil, cultivation, nor fertilization seem to afford an adequate explanation of the high yield per acre.

That the climate of New England could be especially favorable to the development of corn or any other crop has seldom been admitted by western enthusiasts. Nevertheless, Huntington, Williams, and Valkenburg (4) find a remarkably close connection between climate and the yield of corn as well as of other crops. They have analyzed the climatic factors of both rainfall and temperature by seasons in respect to yield of corn per acre. They based their study on the average yield

for 16 years in all the states outside of New England where corn is produced in reasonable quantities without irrigation. In this way they found that the highest yields were obtained when all four of the seasons, including even the winter, were identical with the average for Connecticut. They found also that in all parts of the world the yield of corn per acre varies in harmony with the climate.

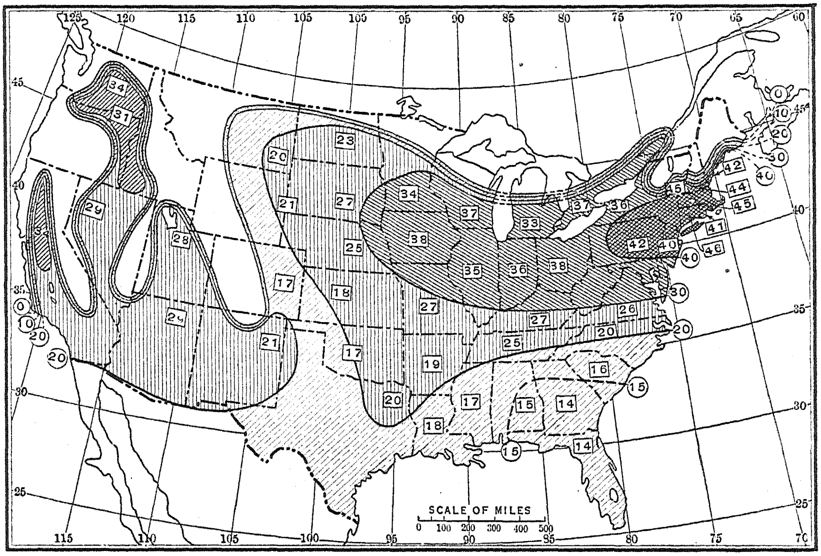

FIG. 2.—Average yield of corn per acre in the United States, 1910–1929, shown by isopleths. (From Huntington, Williams, and Valkenburg's *Economic and Social Geography*. By courtesy of John Wiley & Sons.)

In other words, for corn, as for every other plant and for animals, there is a definite climatic optimum. This optimum includes not only the summer but the rest of the year. If only three months—May, June, and July—are favorable and all the rest of the year highly unfavorable the yield may be only 10 bushels per acre. As the length of the favorable period increases, the yield also increases. The apparent reason why Iowa in spite of its excellent soil fails to equal the southern New England and Middle Atlantic states and only rises to the same level as Ohio and Maryland is that cold, dry winters, an occasional dry spring or fall, and excessive heat during dry spells in summer do more damage than in the states farther east.

The general distribution of the yield of corn per acre in the United States is shown in Fig. 2. Starting in Connecticut, where the yield is highest, the averages fall rapidly toward the north and more slowly toward the south along the Atlantic coast, reaching a minimum of 14 bushels in Georgia and Florida. From southern New England directly westward the average yield falls steadily. On the map there appears to be an exception because Indiana and Illinois rank lower than Iowa, but if only the northern parts of these states and of Ohio were included the exception would probably disappear. It is notice-

able, however, that from southern New England westward there is a belt of high yield which has its western limit in southeastern South Dakota and northeastern Nebraska. In spite of the obvious effect of aridity in Nebraska and Wyoming, this belt extends still farther westward. Among the Rocky Mountains, to be sure, it is interrupted, for practically no corn grows there because of the high altitudes and low temperatures. In Washington, however, the belt of high yield per acre reappears. Northward from this belt the yield of corn everywhere decreases very rapidly until low temperature prevents the crop from being grown; southward the yield diminishes slowly.

From these facts and from the distribution of corn elsewhere, Huntington, Williams, and Valkenburg deduce the rule not only that corn has a distinct climatic optimum, but that *the yield per acre is highest near the coldward limit of possible cultivation*. This is true not only for corn, but for many other crops in this country and in other parts of the world.

With this brief outline of the important climatic conditions governing crop production before us, let us now consider another general rule of crop adaptation that seems to develop from this study of the behavior of corn from widely different regions. *Corn may be moved from a less favorable to a more favorable climatic region without loss of productive capacity, and usually with distinct gain*, provided the length of the growing season permits satisfactory maturity. If this be true, a new variety originating in Indiana, for example, would presumably do still better in Pennsylvania; one originating in Nebraska would show similar improvement when moved to Iowa. Adaptation to different soil types and levels of fertility must, indeed, be taken into consideration, especially where deficient elements are not supplied by proper fertilization. In our tests in Connecticut, however, marked differences in types of soil have not made much difference in relative performance.

The converse of the law italicised above is also true. It may be stated in another form as follows: *Most of the loss in productivity when seed corn is taken from one region to another is due to less favorable conditions of climate*. In many, perhaps most, cases the varieties originating in the more favorable climates seem to lack the power to resist the heat and drought of the less favorable regions. The good varieties taken from the less favored to the more favored climatic areas seem to have a virility which causes them, for a while at least, to excel the varieties originating in the most favored areas.

From all this it seems clear that these climatic relationships must have a tendency to cause good varieties to be moved toward the localities that are climatically most favorable. Suppose a new variety is produced in Georgia and gives an average yield of 16 bushels per acre instead of 14, which is now the rule for all varieties. If it is moved to North Carolina it may be expected to increase its yield in the ratio of even more than 14 to 20, which is the average relation between the yields per acre in these two states. This might mean a yield of 23 or 24 bushels per acre. So good a variety would naturally be carried farther north with still better results. Its northward movement would be checked only when the growing season became too short.

On the other hand, a variety originating in the northeastern United States within the heavily shaded optimum area of our map is likely to suffer the opposite fate. No matter which way it is moved it is likely to be less productive than in its original home. If it has become well adapted to the relatively cool summer of a state like Connecticut, it suffers from the heat when it is moved westward or southward.

Much of the prejudice against seed corn from a distance is no doubt due to the fact that seed is more generally moved, in the central states at least, from the better to the poorer corn growing regions. When a farmer is seeking new seed he goes to the neighbor that produces better corn than he does. When seed must be brought into a region on account of a crop failure only the more favored sections have seed to send. Most commercial seedsmen produce their crops in those locations where the most attractive crop can be grown at the lowest cost.

In some cases, when improved varieties are moved away from the optimum area, they produce more abundantly than the local varieties in the new area, even if not so abundantly as in their place of origin. More exact information is needed on this point. It is hoped that this article will call attention to the desirability of widespread experiments in which seed corn shall be exchanged between widely separated regions in such a way as to test all sorts of climatic relationships.

As a step in this direction, the facts set forth in this article seem to shed new light on the perplexing problems of why the yield of corn varies so greatly from region to region and of what conditions determine how seed may most profitably be transferred from one region to another. Both problems are involved in the question of the precise conditions which enable Connecticut and the surrounding regions to raise so much more corn per acre than any other sections. The most fundamental condition seems to be that here the climate is almost ideal for corn *at all seasons*. The summers are sufficiently warm and rainy, but are not often subject to either extreme heat or extreme drought. The growing season is fairly long, and both the spring and fall rarely experience droughts or unseasonable frosts which produce any such extreme effects as are common farther in the interior in the same latitude. And finally, the winters are only moderately cold and have sufficient rain and snow. Hence the soil is generally saturated with moisture in the spring. This reduces the danger that the thin but highly valuable upper layer of soil will be blown away by the wind or that the soil as a whole will be so dry as to hamper the growth of the seed. Any departure from this optimum, even in winter, appears to lessen the yield of corn per acre. Thus, in transporting seed from one section to another we need to take account not only of the summer but of the whole year. In this way we can form a fairly good estimate of how well the transported seed will thrive and what yield it will give. In general, unless it is moved too far, any given variety might be expected to vary from state to state in approximately the same way that the average yield of all varieties varies over long periods as shown on the map. There is some indication, however, that the change to another climate produces an even greater effect than would be expected on this basis.

A second broad generalization also needs emphasis. The concentration of high yields of corn in a northern belt from Connecticut to Iowa is reenforced by other causes in addition to the direct effect of climate. These other causes, to be sure, are also climatic, but only indirectly. The first of them is soil. In a broad way the best quality of soil is produced where the climate is medium in two respects. The medium in one respect is found about half way from the equator to the poles in about the latitude of the greatest productivity of corn. The other is found in the grassy regions midway between the eastern forests and the western or central arid regions of a continent. Iowa, with its wonderful soil, is like the Ukraine of Russia in being located where both of the favorable types are combined.

Another factor, indirectly climatic, which determines the northward location of the belt of maximum yield per acre is the prevalence of pests. Many of these, such as the corn ear worm, weevil, and bacterial wilt, thrive in the South but are hampered by cold winters in the north. A human factor is probably still more important. For centuries the mere fact, that, when seed corn is transported northward, its productivity increases, has presumably resulted in a strong tendency to carry good types of seed northward. The opposite tendency has been discouraged because northern seed when carried south in our hemisphere yields less than in its original habitat. Many local factors of both soil and climate undoubtedly modify the general rules as to the climatic optimum and the northward concentration of high yields. Nevertheless, the experience of Connecticut with both field and sweet corn tends to confirm these wide generalizations.

LITERATURE CITED

1. White, George C., and Johnson, Robert E. Corn silage feeding investigations: V. Relative feeding values of the dry matter of different types of silage corn ensiled at different stages of maturity. Conn. (Storrs) Agr. Exp. Sta. Bul. 159 : 315–323. 1929.
2. Jones, D. F., Slate, W. L., and Brown, B. A. Corn in Connecticut. Conn. Agr. Exp. Sta. Bul. 259 : 383–470. 1924.
3. Collins, G. N. New-place effect in maize. Jour. Agr. Res. 12 : 231–243. 1918.
4. Huntington, Ellsworth, Williams, Frank E., van Valkenburg, Samuel. Economic and Social Geography. New York: John Wiley & Sons. 1933.

BORON DEFICIENCY IN TOBACCO UNDER FIELD CONDITIONS[1]

J. E. McMurtrey, Jr.[2]

THE present definite trend in the fertilizer industry toward the use of relatively pure chemicals to replace the much more complex materials previously employed has accentuated the need of an adequate knowledge of the effects on plant growth of all essential elements. Obviously, use of the highly concentrated materials as the chief or sole sources of nitrogen, phosphorous, and potassium may result in mixtures containing little, if any, of various other elements known to be essential for the higher plants. That boron is an essential element for higher plants has been demonstrated by several investigators in recent years (1, 2, 3, 4, 5, 6, 7).[3] In previous papers (4, 5), the writer has described the distinctive effects of boron deficiency on the growth of tobacco. It was pointed out also (4) that it is possible to obtain symptoms of boron deficiency in pot cultures using field soil.

As far as is known the occurrence of boron deficiency under field conditions has been described only from Sumatra (3) where it is reported to produce a characteristic disease of tobacco known as top-sickness (Topziekte).

METHODS OF EXPERIMENTATION

A series of plats to study the effects of varying rates of calcium application on yield and quality of tobacco was started in 1928 and tobacco has been grown on them each year since then. The plats were located at Upper Marlboro, Md., on a phase of the Collington series which is quite sandy and could probably be designated as loamy sand with some gravel admixture. The fertilizer mixture was prepared from mono-ammonium phosphate, calcium nitrate, ammonium nitrate, potassium sulfate, and magnesium sulfate. None of these salts were of the C. P. grade. The materials were applied each year in quantities to furnish 80 pounds of nitrogen (N), 80 pounds of phosphoric acid (P_2O_5), 100 pounds of potash (K_2O), and varying quantities of calcium per acre. Since the quantities of calcium furnished are not to be discussed in this paper, it is sufficient to state that 115 pounds of CaO were supplied as calcium nitrate on the plats under consideration. Magnesia (MgO) was applied at the rate of 20 pounds per acre and sulfur at the rate of 125 pounds of SO_3 per acre.

DISCUSSION OF RESULTS

In 1933 the tobacco developed the characteristic die-back of the terminal bud previously described (4, 5) as distinctive for boron deficiency when the plants were grown in solution cultures and in pot

[1]Contribution from Division of Tobacco and Plant Nutrition, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating with Maryland Agricultural Experiment Station. Received for publication January 17, 1935.

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[3]Figures in parenthesis refer to "Literature Cited," p. 273.

cultures with soil and sand. Since this condition was more or less common on all treatments, there was no absolute check as to whether it was due to boron shortage. However, on a plat in another series fertilized with a mixture in which the potash was derived from a commercial potassium chloride containing boron, this die-back of the terminal bud was not observed.

In order to determine if the diagnosis of this trouble was correct, boron was applied in 1934 at the rate of 5 pounds per acre of chemically pure boric acid (H_3BO_3) to two plats and omitted from duplicate treatments in this series.

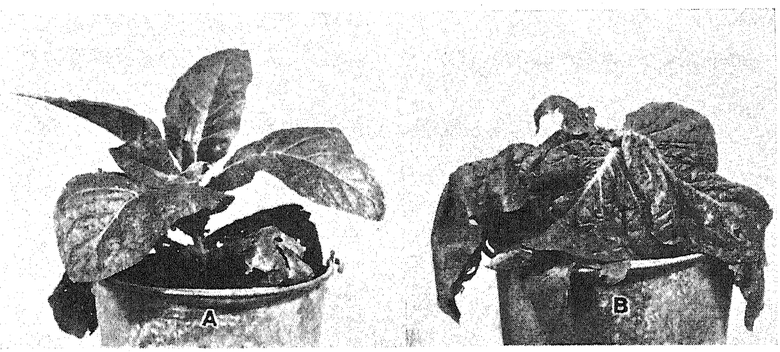

FIG. 1.—Tobacco plants from field transplanted to buckets to facilitate photographing. A, early manifestations of boron deficiency characterized by light green color at the base and drawn appearance of bud leaves. B, extreme boron deficiency showing die-back of the terminal bud, rolling of upper leaves, and associated phenomena.

On plats which received no boric acid the characteristic effects of boron deficiency again were apparent, being particularly marked on one of them. The effects did not develop where boron was supplied. It is important to call attention to the fact that boron may become toxic to plant growth unless used in very small quantities. No toxicity was observed with the quantity used in this instance.

The following are distinctive effects of boron deficiency on tobacco. First, the young leaves composing the bud exhibit a light green color, the bases of the individual leaves manifesting a lighter green than the tips. When this condition appears, the bud leaves have ceased to grow and exhibit a somewhat drawn appearance as seen in Fig. 1, A. This condition is followed by a breaking down of the tissue at the base of the young leaves making up the bud. Death of the terminal bud is the final manifestation, as shown in Fig. 1, B. The automatic topping of the plant results in a thickening and an increase in area of the leaves. Finally, the leaves become glabrous and brittle, and when the midrib is broken, the vascular tissue shows discoloration. The upper leaves tend to roll in a half circle downward from the tip toward the base (Fig. 1, B). When the boron deficiency is not too extreme so that lateral buds (suckers) develop in the axils of the leaves or at the base of the stalk, these generally break down, as described above.

When the earlier stages do not progress too far and the young leaves later make fair growth, they may be distorted by twisting to one side because of growth around the injured tissue. The stalk toward the top of the plant in the same fashion may show a one-sided or twisted growth.

SUMMARY

The recent trend toward the use of relatively pure chemicals in the fertilizer industry emphasizes the importance of all elements essential to plant growth. After using such chemicals in preparing fertilizer mixtures for tobacco on a sandy soil for a period of 5 years pronounced effects of boron deficiency became apparent.

The first indication of boron deficiency is a light green color of the bud leaves especially at the base of the individual leaves, which is followed rapidly by more or less breakdown of the tissue. When the breakdown does not involve all the tissue and later growth takes place, such leaves are distorted by growth around the injured areas. In the same manner the stalk toward the top of the plant may manifest a one-sided or twisted growth. The final manifestation is a dieback of the terminal bud. Lateral buds (suckers) may develop in the axils of the leaves or at the base of the stalk, but they usually break down as described above.

LITERATURE CITED

1. BRENCHLEY, W. E., and WARINGTON, K. The role of boron in the growth of plants. Ann. Bot., 41 : 167–187. 1927.
2. JOHNSTON, E. S., and DORE, W. H. The relation of boron on the chemical composition and growth of the tomato plant. Plant Physiol., 4 : 31–62. 1929.
3. KUIJPER, J. Boorzuur tegen de topziekte van de tabak. Deli-Proefsta. Medan. Vengschr., 50, 7 pp. 1930.
4. McMURTREY, J. E., JR. The effect of boron deficiency on the growth of tobacco plants in aerated and unaerated solutions. Jour. Agr. Res., 38 : 371–380. 1929.
5. ————. Distinctive effects of the deficiency of certain essential elements on the growth of tobacco plants in solution cultures. U. S. D. A. Tech. Bul. 340 : 1–42. 1933.
6. SOMMER, A. L., and LIPMAN, C. B. Evidence on the indispensable nature of zinc and boron for higher green plants. Plant Physiol., 1 : 231–249. 1926. illus.
7. SWANBACK, T. R. The effect of boric acid on the growth of tobacco plants in nutrient solutions. Plant Physiol., 2 : 475–486. 1927.

THE RELATION OF VARYING RAINFALL TO SOIL HETEROGENEITY AS MEASURED BY CROP PRODUCTION[1]

W. H. METZGER[2]

THIRTY-SIX field plats, each 1/20 acre in size, were established at the Kansas Agricultural Experiment Station in 1925 for the purpose of expanding the soil fertility investigations. Careful examination of profile samples showed no marked variations in the physical constitution of the soil of the area covered by these plats. It was considered desirable, however, to crop the plats uniformly for a few years before treatments were inaugurated in order to determine natural variability of the soil. Shortage of funds delayed the beginning of the fertilizer treatments longer than had been planned with the result that the plats have now been uniformly cropped for 10 years. Yields have been obtained in only 9 years, however, because an exceedingly heavy chinch bug migration in 1933 resulted in the loss of a crop of Atlas sorgo.

During this period of years rainfall varied greatly and field observations indicated that the amount of rainfall was an important factor influencing the variability of the crop-producing power of the soil. The yields confirmed these observations. A study has, therefore, been made of this relationship.

MATERIALS AND METHODS

The crops grown in the 9 years were as follows: 1925, corn; 1926, oats; 1927, wheat; 1928, wheat; 1929, alfalfa; 1930, alfalfa; 1931, alfalfa; 1932, Atlas sorgo; 1934, Atlas sorgo. The 1933 crop was lost as explained previously. The mean yields and the deviations for each crop were determined. The deviation of the yield of each plat from the mean was expressed as percentage of the mean and the values so obtained were averaged. This method of expressing variability was used by Garber and Hoover (2)[3] and by Garber, McIlvain and Hoover (3) and affords a measure of such variability based directly on actual yields.

RAINFALL AND YIELD VARIABILITY

The yields of the various crops during the 9 years failed in a large proportion of the cases to show the persistent soil differences which were reported by Harris and Scofield (4) and by Garber and Hoover (2). Certain plats rather consistently ranked high in yield and others fairly regularly ranked low, but the great majority of the plats were erratic in their yield performances. It was believed this might be the result of moisture supply being the dominant limiting factor in crop production in certain years rather than any nutrient deficiency. The

[1]Contribution No. 242 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication January 14, 1935.

[2]Assistant Professor of Soils. The field work yielding the results on which this study was based was directly supervised by Dr. F. L. Duley during the years 1925–1931.

[3]Figures in parenthesis refer to "Literature Cited," p. 278.

uneven appearance of crop growth in the dry years as contrasted with a more uniform appearance in normal seasons strengthened this belief.

In studying the relationship of rainfall to these yield variations the period of September 1 to September 1 was selected as that best representing an effective rainfall year for the six grain-producing crops, corn, oats, two crops of wheat, and two crops of Atlas sorgo. The three alfalfa crops were considered separately because no crop year basis could be selected which included to a similar extent the effective rainfall for the alfalfa crops and the grain-producing crops. The total annual yield of alfalfa at Manhattan is usually largely determined by the first and last cuttings and therefore rainfall after September 1 often greatly influences the yield for the current season.

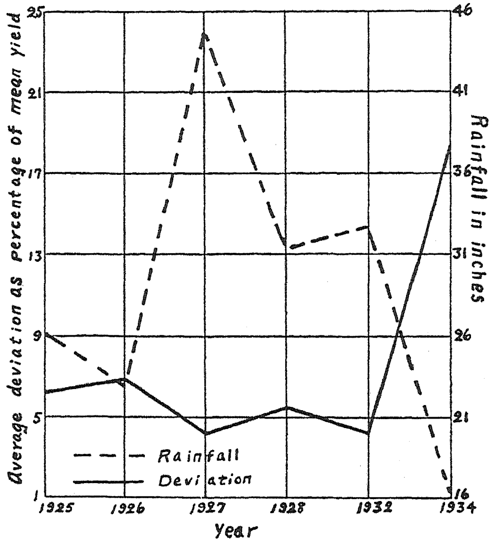

FIG. 1.—Curves showing the inverse relationship between rainfall and variability of crop yields.

The rainfall and the variability of the yields of the grain-producing crops for the years 1925, 1926, 1927, 1928, 1932, and 1934 are presented in Table 1. Yields in all cases represent total produce, that is, grain plus straw or stover as the case may be, except for the year 1925 when the yield of corn stover was not determined.

TABLE 1.—*Rainfall and variability of yields of grain-producing crops from 36 uniformly cropped plats.*

Year	Rainfall, Sept. 1 to Sept. 1, inches	Yield deviations expressed as percentage of the mean
1925	26.17	6.46
1926	22.69	7.28
1927	45.02	3.97
1928	31.32	5.47
1932	32.64	4.04
1934	16.15	19.11

The data of Table 1 are shown graphically in Fig. 1. It is strikingly evident that a high negative correlation exists between the rainfall and the extent of variability of the crop yields. The correlation coefficient was calculated and found to be: $r = -.772 \pm .111$.

This coefficient was calculated on the basis of an assumption that the relationship was linear. A somewhat higher value might have been obtained by the use of the formula for the coefficient for a non-linear relationship, but the value here given indicates a highly significant negative correlation.

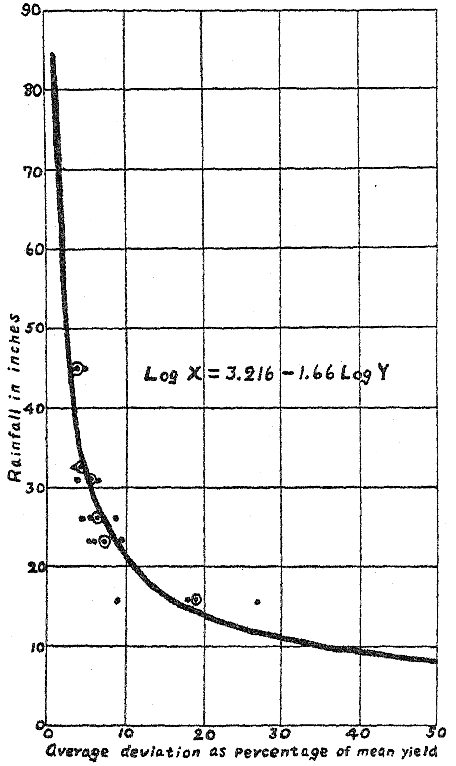

FIG. 2.—Regression of yield deviations on rainfall for six grain-producing crops, corn, oats, wheat, wheat, Atlas sorgo, and Atlas sorgo.

A dot chart is presented in Fig. 2 in which the rainfall is plotted against the percentage deviation, the values from Table 1 being shown as dots inclosed by circles. Since the 36 plats are divided into three series of 12 plats each, the values for each series are also shown, the dots in this case not being circumscribed. The use of these dots shows more completely the spread of the percentage deviation values for the various plats. The regression is non-linear and may be represented by the equation:

$$\log x = 3.216 - 1.66 \log y.$$

The data and curves indicate clearly that low rainfall, under the conditions existing at Manhattan, Kans., brought about high variability in the crop-producing power of the soil of these plats. When rainfall was adequate the soil produced much more uniform crops.

Such a relationship is perhaps common to areas where rainfall is frequently a limiting factor in crop production. Support for this affirmation is supplied in data assembled from a publication by Finnell (1) of the Oklahoma Experiment Station. These data are presented in Table 2.

The correlation coefficient for Finnell's data was calculated and found to be $r = -.9149 \pm .0449$. The regression is non-linear. The same principle is illustrated in the data from the two sources, Oklahoma and Kansas, namely, that a low moisture supply increases soil heterogeneity as measured by crop yields and high moisture supply produces greater uniformity.

Using calendar year rainfall figures, since the calendar year fulfills the requirement of a good crop year for alfalfa, the percentage devi-

ation values for the alfalfa crops of 1929, 1930, and 1931 show a similar relationship to rainfall. These values are listed in Table 3.

TABLE 2.—*Available moisture in the surface foot of soil and the coefficient of variability of crop yields, 9 years (Finnell).*

No. of plats	Depth of subsoil, feet	Culture	Average percentage available moisture	Coefficient of variability of yield
1.......	6	Continuous wheat	6.83	107.6
1.......	4	Continuous wheat	5.19	112.2
2.......	6	Wheat-fallow	8.96	75.2
2.......	4	Wheat-fallow	7.24	83.8
3.......	6	Wheat-fallow-fallow	8.29	77.4
3.......	5	Wheat-fallow-fallow	8.05	81.0

TABLE 3.—*Rainfall and percentage deviation of alfalfa yields.*

Year	Rainfall Jan. 1 to Jan. 1, inches	Yield deviations expressed as percentage of mean yield
1929..................	33.65	10.37
1930..................	34.18	8.06
1931..................	38.75	4.88

The correlation coefficient for the alfalfa crops was found to be $r = -.936 \pm .048$. Despite the extremely high correlation indicated by this value, no great validity is attached to these data. Only three measurements are involved and the spread in rainfall values is not great. Considered along with the preceding data, however, the values for alfalfa lend weight to the previously presented evidence regarding the influence of rainfall on soil heterogeneity as reflected in crop yields.

The existence of this type of relationship does not increase confidence in the results of field investigations as they are frequently conducted, especially in regions where rainfall is often deficient. The results emphasize the need for consideration of the use of smaller plats and more replications in field experiments than are frequently employed.

Summerby (5) has recently presented data showing the need for replication even where preliminary uniform cropping has been practiced for the purpose of measuring variability in the soil.

SUMMARY

The variability of crop yields from uniformly cropped field plats receiving no fertilizer, manure, or lime treatments was studied in relation to rainfall. High negative correlations were found between rainfall for the "crop year" and soil heterogeneity as reflected in crop yields. Calculations from data assembled from a publication of the Oklahoma Experiment Station show a similar relationship between moisture supply in the soil and yield variability.

The existence of such a relationship emphasizes the need for smaller plats and more replications in many field experiments. It also decisively limits the value of a uniform cropping period as a means of establishing definite variability in the crop-producing power of a group of experimental plats.

LITERATURE CITED

1. FINNELL, H. H. Moisture and fertility relations of subsoil variations in heavy silt loam soil at Goodwell, Oklahoma. Okla. Agr. Exp. Sta. Bul. 214. 1933.
2. GARBER, R. J., and HOOVER, M. M. Persistence of soil differences with respect to productivity. Jour. Amer. Soc. Agron., 22 : 883–890. 1930.
3. ————, McILVAINE, T. C., and HOOVER, M. M. A method of laying out experiment plats. Jour. Amer. Soc. Agron., 23 : 286–298. 1931.
4. HARRIS, J. ARTHUR, and SCOFIELD, C. S. Further studies on the permanence of differences in the plots of an experimental field. Jour. Agr. Res., 36 : 15–40. 1928.
5. SUMMERBY, R. The value of preliminary uniformity trials in increasing the precision of field experiments. Macdonald Col. (McGill Univ. Prov. of Quebec, Canada) Tech. Bul. 15. 1934.

UNIFORMITY TRIALS WITH RICE[1]

CHIEN-LIANG PAN[2]

MODERN systems of field plat technic, together with the new statistical method of interpreting data known as the "Analysis of Variance," have been introduced. The use of systematically replicated plats with frequent check plats for correction of yields is not as prevalent today as it was a few years ago. In their place randomized blocks have been substituted. Unfortunately, however, few comparisons of the mathematical reliability of the two methods have been made with actual data. In the present paper the two methods are compared and a study is made also of the comparative efficiency of plats of different sizes.

LITERATURE REVIEW

In 1933 Love (7)[3] introduced a method into China for the breeding of rice varieties similar to the method used at Cornell University (5, 6). Student's method, originally used for interpreting the data of advanced tests, was abandoned and Bessel's formula for calculating the probable error was used for all comparisons. By this method a probable error was calculated from the check plats and expressed in percentage of the mean. This average probable error in percentage of the mean was multiplied by the square root of 2, to obtain the average probable error of a difference in percentage. The average yield of each strain was computed and its gain or loss as compared with the yield of its theoretical check was calculated. The probable error of this gain or loss was computed by multiplying the average yield of each variety or strain by the percentage probable error of a difference. For significance, the gain of a strain over its theoretical check should be at least 3 times the probable error of a difference.

The use of randomized blocks as devised by Fisher (1) appears to be a promising method of making preliminary comparisons of strains obtained from head selections. By use of Fisher's (2) analysis of variance it is possible to divide the total variance into its components, thus allowing for the removal of the variance due to known causes, such as blocks and varieties.

The relative desirability of different sizes and shapes of plats was studied by Immer (3), who worked with sugar beets; by Kalamkar (4), who worked with potatoes; and by Lord (8), who worked with rice. In general, these studies indicated that the experimental variability was decreased when the size of plat was increased and that long narrow rows were preferable to short wide ones.

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[1]Contribution from the Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. These data were taken when the writer was Junior Agronomist at the Provincial Agricultural Experiment Station of Chekiang, China. The paper was submitted to the Graduate School of the University of Minnesota as partial fulfillment of the requirements for the degree of master of science, June 1934. Received for publication January 21, 1935.

[2]Graduate Student. The writer wishes to express his appreciation to Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics under whose personal direction the statistical studies were made.

[3]Numbers in parentheses refer to "Literature Cited," p. 285.

MATERIALS AND METHODS USED

Three varieties of rice were used in this study. Two were medium-maturing varieties with a growing period of approximately 130 days and the other a late-maturing variety with a growing period of more than 150 days. One of the two medium-maturing varieties and the late-maturing variety were grown in the rice breeding nursery field at the central station of the Provincial Agricultural Experimental Station of Chekiang, China, located at Hangchow. The other medium-maturing variety was grown at the substation located at Wufu about 70 miles from the central station.[4]

The method of direct planting in the row was used instead of transplanting. The medium-maturing varieties were planted in 1931 early in May, and the late-maturing variety was planted early in June. The varieties were harvested in the middle of September and early in November, respectively. Rectangular fields consisting of three series of 100 rows each were used for each variety. Each row was 14.2 feet long with a 1.5 foot space between the rows. Each series was separated by a 2-foot alley and the rows ran from north to south. The medium-maturing varieties were sown at the rate of 10 grams per row, while for the late variety only 8 grams per row were used. The calculated yield in bushels per acre for single row plats was obtained by multiplying the yield in grams by 0.1.

EXPERIMENTAL RESULTS

SIZE AND SHAPE OF PLATS

The study was made on the basis of 25 varieties to be tested. If these were to be tested in single-row plats much less land would be needed than for three-row plats. As a rule larger areas of land are more heterogeneous than smaller areas and, therefore, the calculations were made on the basis of the actual area that would be used in a test of 25 varieties. There were, however, 300 rows in all in each of the three studies; consequently, the study of variance in single-row plats comprised 12 groups of 25 rows each. The data presented represent the average variance for single-row plats with the block differences removed. Similarly, for two-row plats the computations were on the basis of the actual area in each group of 25 hypothetical varieties.

Two methods were used for determining the most desirable size and shape of plats in order to find whether it is more desirable to increase the width or the length of the row. Four different widths of plats were studied, namely, single-row, two-row, three-row, and four-row plats. The single-row plat comprised an area of 21.3 square feet, while the areas covered by two-, three-, or four-row plats were 2, 3, or 4 times as great. Three different lengths of row were studied, namely, single-row, two-row, and three-row length. The area of these three different lengths of rows was the same as the area of plats one, two, or three rows in width. The yield of plats of two-row length was obtained by adding the yields of the corresponding rows in the first and second series for the study designated as A, and by adding the yields of rows in the second and third series for the study designated as B.

The calculated results for the different sizes and shapes of plats are given in Table 1. The data in Table 1 give the efficiency index of the

[4]The writer is indebted to H. N. Shen who furnished the data used.

different sizes and shapes of plats. This index was calculated by dividing the variance of a single-row plat by the product of the variance of a multiple-rowed plat times the number of rows included in this plat and expressing the result in percentage.

TABLE 1.—*The experimental variability for different sizes and shapes of plats of the two rice varieties grown at the Hangchow Central Station and of the variety grown at the Wufu Substation.*

Size and shape of plats	Medium-maturing variety grown at the Hangchow Central Station		Late-maturing variety grown at the Hangchow Central Station		Medium-maturing variety grown at the Wufu Substation	
	Variance	Efficiency	Variance	Efficiency	Variance	Efficiency
1-row	35.049	100.00	27.697	100.00	49.036	100.00
2-row	16.066	109.08	15.720	88.09	45.955	53.35
3-row	14.084	82.95	10.392	88.84	46.047	35.50
4-row	12.286	71.32	11.547	59.96	39.480	31.05
2-row lengths, A	29.836	58.74	17.655	78.44	28.228	86.86
2-row lengths, B	24.396	71.83	18.976	72.98	36.389	67.38
3-row lengths	21.500	54.34	14.874	62.07	23.358	69.98

The data in Table 1 show that the single-row plat was the most efficient with the exception of the two-row plat of the Hangchow medium-maturing variety in which case the efficiency was 9% greater than the single-row plat. The data from Hangchow show that the increase in width of plat was more efficient than increase in length of plat, while in the experiment conducted at Wufu increasing the length of row was more efficient than increasing the width of row.

REPLICATION, RANDOMIZED ARRANGEMENT

Five replicated plats were used with 20 hypothetical varieties for each series of the experiment. Randomization was made by Tippett's method, and the analysis of variance was used for interpreting the data. The errors due to varieties and blocks were removed from the total sums of squares and the mean square for remainder was used as the experimental error. The standard deviation for a single determination expressed in bushels is the square root of the mean square for error. This may be converted into a generalized standard error in percentage for a mean of five replicated plats by the formula $\frac{\text{S. D.} \times 100}{\text{m}\sqrt{5}}$, where m refers to average yield and S. D. refers to standard deviation of a single determination in bushels. In order to study the efficiency of the randomized block method, comparisons of yield between the hypothetical varieties were made. There were 190 possible comparisons between these 20 varieties. The standard error in bushels of each hypothetical variety was obtained by multiplying the average standard error in percentage for five replicated plats by the mean yields of five rows of each hypothetical variety. The formula $\sqrt{(\text{S. E.})_1^2 + (\text{S. E.})_2^2}$ was used for calculating the standard error of the

difference between two varieties. After the differences in yields and standard errors between varieties were obtained, the next step was to find how many of these differences fell within 0.5, 1.0, 1.5, etc., times the standard error. The observed data are given in Table 2.

TABLE 2.—*Number of differences in yield between all possible comparisons within the hypothetical varieties that fell within 0.5, 1.0, 1.5, etc., times the standard error of a difference.*

Class ranges	Mathematical expectation	Hangchow medium-maturing variety	Hangchow late-maturing variety	Wufu medium-maturing variety
0.00–0.50 x S. E.	218.25	241	222	235
0.51–1.00 x S. E.	170.89	164	173	197
1.01–1.50 x S. E.	104.71	84	104	79
1.51–2.00 x S. E.	50.22	49	50	44
2.01–2.50 x S. E.	18.87	24	11	10
2.51–3.00 x S. E.	5.53	6	9	5
3.01–3.50 x S. E.	1.25	2	1	0

In Table 2, the class ranges set up are inclusive, that is the class 0.00–0.50 times standard error includes all deviations less than 0.5 times standard error or equal to it, while the class 0.51–1.00 times standard error includes deviations of more than 0.5 times standard error but including those equal to 1 times the standard error.

According to the law of probability, individuals differing from the mean by a magnitude of not more than 0.5 times the standard error of a difference comprise 38.29% of the total population. This percentage was multiplied by the total number of comparisons, giving the expected number of differences falling within the class 0.00–0.50 x S. E. The mathematical expectation of the other classes was calculated in a similar manner. A X^2 test for determining the agreement between observed results and mathematical expectation was calculated separately for each of the three experiments. In calculating the X^2 value, the classes with less than five individuals were combined. For example, the classes 2.51–3.00 x S. E. and 3.01–3.50 x S. E. of the medium-maturing variety grown at Hangchow were combined because there were but 1.25 calculated individuals in the latter class. The calculated values of X^2 and P are given in Table 3.

TABLE 3.—*The calculated values of X^2 and P of the three experiments for determining the agreement between the observed number of differences and mathematical expectation.*

Experiments	D/F	X^2	P
Hangchow medium-maturing variety	5	8.3890	.1435
Hangchow late-maturing variety	5	4.9078	.4350
Wufu medium-maturing variety	5	16.9946	—

The P values of the two experiments carried out at Hangchow exceeded 0.05 so the observed distribution of differences was considered to agree with mathematical expectation. The X^2 value of the Wufu

medium-maturing variety was 16.9946 which was greater than the value for P of 0.01. That is to say, such a deviation of the observed differences from the mathematical expectation would occur less than 1 time in 100 due to chance. It may be of interest to point out that in this experiment the discrepancy between observed and mathematical expectation was chiefly due to a larger number of comparisons in the classes 0.00 to 1.00 S. E. and a correspondingly smaller number in the higher classes.

REPLICATION, SYSTEMATIC ARRANGEMENT

Five replicated plats arranged systematically were used for each hypothetical variety with every fifth row as a check. Two methods were used for calculating the theoretical check. One was to consider the average of the two nearest checks as the theoretical yield for the rows in between the checks. The second was to grade the yields between checks as used by Love (5, 6, 7). The next step was to calculate the gain or loss in yield of each variety over its theoretical check. This was computed by direct subtraction of the yield of a variety from its theoretical check. The standard errors were calculated for each set of five replicated check plats by the formula $\sqrt{\frac{S(D^2)}{n(n-1)}}$, where D is the difference between the mean of each set of five plats and the yield of the individual plats and n is the number of replications. After the standard error of each set of the check plats was calculated, the generalized standard error in percentage was obtained by averaging the standard error of all sets of the check plats and then dividing the average standard error by the mean yield of the check plats and multiplying by 100. This generalized standard error in percentage, multiplied by the mean yield of five replicated plats of each hypothetical variety, gives the standard error in bushels of the variety. This standard error is then multiplied by the square root of 2, giving the standard error of a difference between the yield of the variety and its theoretical check. The number of differences in yield between the hypothetical varieties and their theoretical checks that fall within 0.5, 1.0, 1.5, etc., times standard error of a difference for the three experiments, together with the X^2 values for testing the agreement between observed and mathematical expectation, is given in Table 4.

The number of comparisons in each experiment was 16 which was too small for testing the agreement between observed number of differences and mathematical expectation. The results from the separate experiments were combined and X^2 test was made. When the theoretical check was calculated by averaging the two nearby checks a calculated X^2 value of 23.6578 was obtained and when the theoretical check was calculated by grading the soil between each two pairs of checks the calculated value of X^2 was 19.8688. Both of these values give a P value smaller than 0.01, showing clearly that the observed differences did not agree with mathematical expectation. The lack of agreement appears to be the result of too many differences in the class 0.00–0.50 x S. E. and too few in the classes 1.01 to 2.00 x S. E.

TABLE 4.—*The total number of differences in yield between a variety and its theoretical check that fall within 0.5, 1.0, 1.5, etc., times standard error of a difference and the X^2 values for testing the agreement between observed number of differences and mathematical expectation.*

Class ranges	Mathematical expectation	Methods of calculating the theoretical checks	
		By av. 2 nearby checks	By grading the yield of variety on the basis of the checks
0.00–0.50 x S. E.	55.14	80	78
0.51–1.00 x S. E.	43.17	39	41
1.01–1.50 x S. E.	26.45	18	17
1.51–2.00 x S. E.	12.69	2	4
2.01–2.50 x S. E.	4.77	2	3
2.51–3.00 x S. E.	1.40	2	0
3.01–3.50 x S. E.	0.32	1	1
D/F	—	4	4
X^2	—	23.6578	19.8688

SUMMARY

1. Three uniformity trials conducted in two rice regions with different environmental conditions in the Chekiang Province, China, were carried out in this study. A different variety was used in each of the three trials. The analysis of variance was used to determine both the most desirable size and shape of plats and the efficiency of randomized distribution of replicated plats. The standard error method was used for determining both the desirability of the use of check plats as a means of correcting yields and the efficiency of a systematic distribution of replicated plats.

2. In general, the single-row plat was more efficient than any other size with but one exception, i. e., the two-row plat of the Hangchow medium-maturing variety which was approximately 9% more efficient than the single-row plat.

3. Increase in width of plat was comparatively more efficient than increase in length of row in the experiments at Hangchow, but an opposite result was obtained with the Wufu late-maturing variety.

4. In the randomized arrangement, the number of differences in yield between all possible comparisons of hypothetical varieties that fell within 0.5 times standard error, 1.0 times standard error, and so forth, was computed. A satisfactory agreement between observed numbers and mathematical expectation was obtained in the two experiments at Hangchow, but in the Wufu experiment P was less than 0.01.

5. With the systematic arrangement the deviations from mathematical expectation were too great to be explained on the basis of random sampling.

LITERATURE CITED

1. FISHER, R. A. The arrangement of field experiments. Jour. Min. Agr., 33 : 502–513. 1926.
2. ———. Statistical Methods for Research Workers. London: Oliver & Body. Ed. 4. 1932.
3. IMMER, F. R. Size and shape of plot in relation to field experiments with sugar beets. Jour. Agr. Res., 44 : 649–668. 1932.
4. KALAMKAR, R. J. Experimental error and the field plot technique with potatoes. Jour. Agr. Sci., 22 : 373–385. 1932.
5. LOVE, H. H., and CRAIG, W. T. Methods and results obtained in cereal investigations at the Cornell Station. Jour. Amer. Soc. Agron., 10 : 145–157. 1918.
6. ———, ———. Methods now in use in cereal breeding and testing at the Cornell Agricultural Experiment Station. Jour. Amer. Soc. Agron., 16 : 109–127. 1924.
7. ———. Directions for rice improvement in China. Chekiang Agr., 1 : 43–72. 1933.
8. LORD, L. A uniformity trial with broadcast rice. Jour. Agr. Sci., 21 : 178–188. 1931.

NODULATION OF PEANUT PLANTS AS AFFECTED BY VARIETY, SHELLING OF SEED, AND DISINFECTION OF SEED[1]

J. F. DUGGAR[2]

THESE experiments were conducted in the field on Norfolk soils near Auburn, Ala. Average nodule numbers were determined at successive dates throughout three growing seasons on samples of plants of comparable age. Periods of severe drought occurred in 1930 and 1933, but rainfall was ample in 1932.

NODULATION BEHAVIOR OF SPANISH AND RUNNER PLANTS

Table 1 records the number of both total and large nodules as found at the final harvest of Spanish and runner peanuts each year. At this time the Spanish plants had reached practical maturity, but the runner plants were still growing and had a considerable portion of their nuts not fully matured.

TABLE 1.—*Average nodule numbers on non-inoculated Spanish and runner type peanut plants at final harvest, 1930, 1932, and 1933.*

Variety	Year	Average number of nodules per plant	
		Total nodules	Large nodules
Spanish........	1930	8.7	2.3
Runner........	1930	69.5	6.5
Spanish........	1932	17.5	10.1
Runner........	1932	235.5	34.8
Spanish........	1933	7.0	3.0
Runner........	1933	75.0	14.8
Spanish........	Av., 3 yrs.	11.0	5.1
Runner........	Av., 3 yrs.	126.7	18.7

Both total and large nodules on runner plants were many times more numerous than on Spanish peanut plants. This held true not only at the final date of harvest, but at every date of examination throughout the 3 years. The runner plants took a decided lead in nodulation at a rather early age and before any difference in extent of leaf surface was obvious. The later maturity and greater succulence of the runner plants during the latter part of the season seemed to offer only a partial explanation of the difference in nodulation. Such dissimilarity in nodulation is surprising in view of the fact that these are mere cultivated varieties within the same species.

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It runs parallel to differences that other investigators have found in the nodulation of certain varieties of soybeans.

In a single experiment made in 1930 and not here tabulated, unhulled seed of the two varieties were inoculated with a pure culture made from the peanut plant. Inoculation unmistakably increased the nodulation of Spanish plants, but did not obviously affect that of the runner plants. The latter, although not artificially inoculated, had many more nodules than the inoculated Spanish plants.

In the experiments with surface disinfection of seed, as reported in a later paragraph, it was found that the runner plants were more intensely nodulated even when the seed peanuts were first disinfected. This indicates that the difference in nodulation was not due to the conveyance of more or different micro-organisms on the runner seed, but was probably due to the symbiotic bacteria naturally present in these several soils being better adapted to the roots of the runner plants than to the Spanish plants.

NODULATION OF PLANTS FROM SHELLED VS. UNSHELLED SEED

Experiments were conducted in three years in which both inoculated and non-inoculated seed peanuts of the Spanish variety were employed. These were planted on unfertilized plats and on other plats supplied with 600 pounds of basic slag phosphate per acre.

When the seed were not inoculated, plants from unhulled and shelled seed, on the average, produced nearly the same number of nodules. The yields of dry nuts and average weight of entire dry plants were also practically the same from the two classes of seed.

On the other hand, when the seed were inoculated, plants from unhulled peanuts had 31 total nodules per plant as the average of five experiments, in contrast with only 18 from shelled seed, and had 11.6 large nodules against only 7.5 from shelled seed. The more intensive nodulation of plants from unhulled seed than from shelled seed, when both were inoculated in a watery suspension of pure culture made from peanut nodules, may be due to the capacity of the unhulled seed, with its greater volume and rougher surface, to convey to the soil more of the inoculum than can the smaller, smoother, shelled seed. The average yield of inoculated plants in five experiments was 11.5 grams of dry nuts per plant from unhulled seed, with their larger nodule numbers, in contrast with 9.0 grams of nuts from shelled seed. The average weight of the entire dry plant from unhulled seed was 24.5 against 19.4 grams from shelled seed.

EFFECT OF DISINFECTION OF SEED ON NODULATION OF PEANUTS

Disinfection of the surface of seed peanuts with chemicals was employed with the initial purpose of determining whether the production of nodules on plants not artificially inoculated would be increased by any nitrogen-fixing organisms conceivably carried over on the peanut hull from the harvest field to the new seedbed. The resulting data indicated that the exclusion of this possible source of these organisms

did not prevent the development of a certain number of root tubercles. Hence, the origin of such nodules as spontaneously occurred on Spanish peanuts growing in a number of experimental fields is evidently to be found in the appropriate micro-organisms naturally present in each of these soils rather than in flora adhering to the seed peanuts.

Successive counts of nodules were made throughout three summers on many hundreds of peanut plants, following planting of unhulled Spanish peanuts, both untreated and treated, with various standard disinfectants. These data, though not uniform for the several chemicals and for the various successive ages at which the plants were examined, are interpreted as showing the following general tendencies: For Semesan (1:200), to exert only at certain early stages of growth an effect apparently mildly favorable to nodulation; for copper sulfate (1:30), and boric acid (saturated solution), to be depressive to nodulation while the plants are young; for mercuric chloride (1:1000), with variations in methods of application, to be variable in effect; and for slight charring of peanut hulls with sulfuric acid, promptly followed by repeated washing, to be apparently stimulating to nodule formation up to at least the blooming stage of Spanish peanuts.

Counts in two summers to ascertain the percentage of a stand following treatments as above of unhulled Spanish peanut seed showed a general tendency for disinfectants to depress germination. The average for 2 years, taking 100 as the stand from untreated seed, was found to be 63% for the charring with sulfuric acid, promptly washed off, and 89% for mercuric chloride, also removed.

SUMMARY

Without artificial inoculation, Spanish peanut plants at harvest averaged only 11 total nodules per plant in contrast with 127 on runner plants. The average number of large nodules per plant was 5 with the Spanish and 19 with the runner variety.

Under the conditions of these field experiments the runner variety, unlike the Spanish, appeared not to be benefited by artificial inoculation.

The planting of shelled in comparison with unhulled seed of Spanish peanuts, when both were without artificial inoculation, was not followed by any consistent differences in nodulation, or aggregate dry weight of nuts per plant, or total plant weight.

On the other hand, when both shelled and unhulled Spanish peanut seed were *inoculated*, plants from unhulled seed averaged significantly larger numbers of both total and large nodules and greater weight per plant of both nuts and entire plant. These advantages of unhulled seed are attributed to their carrying larger amounts of inoculum into the soil because of their greater size and rougher surface.

Soaking unhulled seed peanuts not artificially inoculated in various disinfectants tended, with most chemicals, to reduce nodule numbers and to reduce germination.

THE NUMBERS OF *RHIZOBIUM MELILOTI* AND *RHIZOBIUM TRIFOLII* IN SOILS AS INFLUENCED BY SOIL MANAGEMENT PRACTICES[1]

R. H. WALKER AND P. E. BROWN[2]

NUMEROUS investigations have shown that soil management practices and cropping systems greatly influence the general microbiological flora of soils. It seems logical, therefore, to assume that such practices would affect the numbers and activities of specific groups of organisms. That this is true in the case of two species of the root nodule bacteria of the Leguminosae, namely, *Rhizobium meliloti* and *R. trifolii*, will be pointed out in this paper.

Factors affecting the growth of the root nodule bacteria have been studied to a limited extent, but most of the investigations have dealt with the organisms when grown in pure culture or in symbiosis with the plant. While these studies have yielded valuable information, they have not indicated directly the effect of soil conditions and cropping systems on the growth and longevity of these organisms in the soil in the absence of the host.

Research on this problem has been slow to develop, primarily because of a lack of suitable methods. It has been practically impossible to determine the numbers of and to study the root nodule organisms in soils in the presence of the natural soil flora. The development of a suitable method for this purpose, however, has opened up new possibilities and the study of the root nodule bacteria in soils has begun.

HISTORICAL

Wilson (4, 5, 6)[3] has made a rather careful and extensive study of the legume bacteria population of soils. He concluded that soils may be or may become an unfavorable habitat for the various groups of legume bacteria, and that the bacteria may largely or entirely disappear from the soil. This disappearance, he concluded, goes hand in hand with increasing acidity of the soil. The bacteria do not seem to be greatly influenced by the frequency of the host in the rotation, for he found that in acid soils the addition of more bacteria resulted in the formation of a larger number of nodules per plant. In a more recent publication (7), he concluded that, although a growing crop may liberate a very large bacterial population in the soil when the nodular tissue decomposes, this population is transitory and probably does not exist for as long a period as 1 year and that the root nodule bacteria dwindle almost to extinction in certain cases.

Lochhead and Thexton (1) determined the numbers of three species of *Rhizobium* at 3- to 4-week intervals for 3 years in areas which for 20 years had been receiving no fertilizer, manure, or artificial fertilizer, respectively. *R. trifolii*, the only species with the host plant in the rotation, was present in much greater numbers than the other rhizobia, not only immediately following clover, but in later

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[2]Research Associate Professor of Soils and Head of Department, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 296.

years when the numbers had ceased to decline. Whereas quantitative differences were slight in the case of *R. trifolii*, the two fertilized soils contained noticeably higher numbers of *R. leguminosarum* (19 to 20 times) and *R. meliloti* (5 and 11 times) than did the unfertilized area.

In making recommendations concerning legume inoculation, one is continuously confronted with the lack of information to serve as a basis for his recommendations. It has been the practice, rather generally, to advocate the inoculation of legume seed if it is to be sown on land where the particular legume, or one belonging to the same cross inoculation group, has not been grown for a number of years. There appears to be no definite information available to indicate the length of time that may intervene between the growing of legume crops without the need for further inoculation. Neither has there been adequate information to indicate the effect of soil conditions on the growth and longevity of the root nodule organisms in the soil after the removal of the legume crop. It is obvious that the character and composition of the soil play a major rôle in determining the growth of these organisms after the legume crop is removed from the land. It follows, therefore, that recommendations concerning legume or soil inoculation should be based upon a complete knowledge of soil conditions, cropping history of the land, and also a knowledge of factors affecting the growth and longevity of the organisms in soils. It seems entirely possible that further research on this problem will yield information of considerable value in determining the need of a particular soil for inoculation. A knowledge of the number of these organisms in a soil will undoubtedly be of much help in this connection.

It was for the purpose of extending our information on this problem that the investigation reported here was initiated.

EXPERIMENTAL

On the Agronomy farm at Iowa State College there are available several series of plats where various fertilizer treatments have been made and different cropping systems have been followed for the past 20 years. The soils ot these plats are admirably suited to the study of factors affecting the number of root nodule bacteria in soils. Hence several of these plats have been sampled, at various times of the year, and the soils examined for *R. meliloti* and *R. trifolii*.

The samples taken for this study consisted of a composite of 16 to 20 subsamples, systematically taken over 1/10 acre plats. Only the surface 4 or 5 inches of soil were sampled. The studies were made by the method developed by Wilson (5) which is a modification of the dilution method for determining numbers of bacteria and is especially adapted to the study of the legume bacteria in soils. In general, this method consists of making several dilutions of the soil to be tested, the highest being beyond the one expected to contain the organisms to be counted. A portion of each dilution is then transferred to tumblers or jars of sterile sand to serve as inoculum. After a few days incubation sterile seed of the particular legume whose symbiont is to be studied is planted in the sand. After sufficient time has elapsed to allow for the development ot nodules on the roots of the young seedlings, usually 2 to 3 weeks, the plants are dug and the roots examined for the presence of nodules. A record is then made of the dilutions carrying the nodule bacteria and from the data thus obtained it is possible to estimate with fair degree of accuracy the minimum numbers of legume bacteria in soils.

The following relatively unimportant modifications from the procedure followed by Wilson have been adopted as a part of the routine in this work. In each instance the seed was sterilized with hydrogen peroxide according to the method

developed by Walker and Erdman (3). All dilutions were made in units of 10, and 10-cc portions of the soil suspension were used in all transfers, including the portions used to inoculate the sterile sand. The plants were grown in sand contained in 1-quart earthenware jars.

It should be made clear that the numbers of legume bacteria as reported in the tables that follow are not claimed to be the exact number in the soils examined. Rather they represent an estimation of the minimum numbers. It was pointed out above that the dilutions were made in units of 10. Hence where a soil is reported as containing 10,000 bacteria per gram it is inferred that there were at least that many present and probably more, the exact number being somewhere between 10,000 and 100,000. That this is a rather wide gap is true, but where this method is employed the large differences only and not the small ones are observable. Hence the differences observed are undoubtedly of real significance.

RESULTS

In one series of tests the numbers of *R. meliloti* and *R. trifolii* were determined in the soils of the variously treated plats of the 2- and 3-year rotation experiments at the Agronomy farm. In each of these experiments there are untreated plats; plats treated with manure and limestone; with manure, limestone, and rock phosphate; and with crop residues and limestone. The manure has been applied to the soil once in the rotation but always at the rate of 2 tons per acre per year. Limestone has been applied when needed to meet the lime requirement of the soil. Rock phosphate has been applied once in the rotation, for the first 10 years at the rate of 500 pounds per acre per year and during the last 10 years at half that amount. The crop residues consist of straw, corn stalks, and other residues and the second crop of clover when that crop is grown. The soil, which is Clarion loam, has been subjected to these treatments for the past 20 years. During that time no legume crop has grown on the plats of the 2-year rotation, but mixed red clover and alfalfa have been grown on the 3-year rotation plats every third year, with corn and oats being grown the other 2 years. During the past 10 years the legume seed has been inoculated with a pure culture of the appropriate organism before seeding.

Under the 2-year rotation there are two blocks of plats so that one of the blocks of plats is cropped to one of the crops of the rotation each year. Likewise, there are three blocks of plats in the 3-year rotation and one of the crops of the rotation is grown on one of the blocks of plats each year. In the experiments reported here soil samples were taken from the blocks of each rotation where corn and oats were being grown. The results obtained in these tests are shown in Tables 1 and 2.

The data of these tables show rather definitely the effects of the soil treatments and the growth of legume plants upon the numbers of *R. meliloti* and *R. trifolii* in this soil. It may be observed that in every instance with one exception, the application of manure and limestone to this soil increased the number of these organisms. This increase was 10-fold in most instances and in some cases even greater.

TABLE 1.—*Numbers of root nodule bacteria per gram of soil in the 2- and 3-year rotation plats, 1934.*

Plat No.	Soil treatment	pH	*R. meliloti*			*R. trifolii*		
			May 1	June 14	Sept. 20	May 1	June 14	Sept. 20
	2-year Rotation, Corn and Oats							
811	Check	6.06*	100	10	100	100	10	100
812	M + L	7.23	1,000	100	1,000	1,000	100	1,000
813	M + L + RP	7.21	1,000	1,000	10,000	1,000	1,000	10,000
814	CR + L	7.23	100†	1,000	1,000	10,000†	1,000	1,000
	3-year Rotation, Corn, Oats, and Mixed Red Clover and Alfalfa‡							
829	Check	5.79	1,000	100	100	10,000	100	100
830	M + L	6.84	10,000	1,000	1,000	10,000	1,000	1,000
831	M + L + RP	6.98	100,000	10,000	100,000	10,000	10,000	100,000
832	CR + L	7.05	10,000	1,000	1,000	10,000	1,000	1,000

*The pH determinations were made on the samples taken Sept. 20.
†Results doubtful.
‡Red clover and alfalfa were grown on the 3-year rotation plats the year previous to sampling the soil.

TABLE 2.—*Numbers of root nodule bacteria per gram of soil in the 2- and 3-year rotation plats, May 22 and Oct. 8, 1934.**

Plat No.	Soil treatment	pH	*R. meliloti*		*R. trifolii*	
			May 22	Oct. 8	May 22	Oct. 8
	2-year Rotation, Corn and Oats					
805	Check	6.11	10	10	10	10
806	M + L	6.91	1,000	100	1,000	100
807	M + L + RP	7.08	100	1,000	1,000	1,000
808	CR + L	6.94	1,000	100	1,000	100
	3-year Rotation, Corn, Oats, and Red Clover and Alfalfa					
817	Check	5.87	100	10	100	10
818	M + L	7.11	10,000	100	10,000	100
819	M + L + RP	6.94	100,000	1,000	100,000	1,000
820	CR + L	7.04	10,000	100	100,000	100

*Oats were grown on all plats in 1934. Red clover and alfalfa were sown with the oats in the 3-year rotation plats but did not grow because of the dry weather.

There was about the same number of these organisms in the soil treated with crop residues and limestone as in that treated with manure and limestone. There is some indication that the limestone is the predominating factor responsible for the increase in numbers of organisms in the soils in these two plats over those found in the untreated soils in the check plats, but the organic matter factor is not isolated from the other, hence it must be given some credit for the increase. Unfortunately, soils treated with limestone only and with organic matter only were not available in this particular group of plats. From a practical standpoint, however, this is not important, for on this type of soil it is recommended that both limestone and manure treatments be made for the best growth of general farm crops,

including the legumes. Hence, under practical conditions as recommended, the combined effect of the two treatments would certainly increase the numbers of root nodule bacteria in the soil.

The application of rock phosphate to this soil in addition to the manure and limestone was responsible for a still further increase in numbers of root nodule bacteria. This increase was as large in most instances as that effected by the manure and limestone, and in some cases it was even larger. This soil, presumably, is somewhat deficient in available phosphate for the growth of higher plants, as it responds fairly well to applications of this fertilizer. This is shown in the yields of crops produced on these plats (2). Apparently, also, this soil is deficient in phosphate for the growth of the alfalfa and red clover root nodule bacteria and is a much better medium for growth after the application of the rock phosphate. Whether the application of phosphate alone to this soil would result in these large increases in numbers of root nodule bacteria is not known. It is very probable, however, that the combination of organic matter, limestone, and phosphate is necessary to effect the large increases in numbers shown by the data.

It may be contended that the larger number of root nodule bacteria in the soil is a result of a better development of the legume crop. This is undoubtedly true in many instances, and especially where the legume crop is being grown on the land frequently in the rotation. It will be observed, however, that the same effect of the soil treatments appeared in the soils of the 2-year rotation where no leguminous host plant has been on the land for the past 20 years. The growing of a legume crop, however, does influence the number of root nodule bacteria in the soil. This is shown by the data of Tables 1 and 2. In most instances there were about 10 times as many root nodule bacteria in the 3-year rotation soils where the respective leguminous host plant has been grown as in the 2-year rotation soils where the host plant has not been grown. This increase in numbers resulting from the growth of the host plant on the land is not as large, however, as one might expect. It appears that the condition of the soil with reference to organic matter, lime, and phosphate has a much larger influence on the numbers of these organisms in this soil than does the frequency of growth of the host plant. These observations are in agreement with those of Wilson (3, 7).

There were approximately the same number of *R. meliloti* and *R. trifolii* in the soil of these variously treated plats. This is true for the soils of the 3-year rotation plats where both alfalfa and red clover are grown and also for the soils of the 2-year rotation plats where neither legume crop has been grown.

In another series of tests the numbers of *R. meliloti* and *R. trifolii* were determined in the soils of the 5-year rotation plats. The rotation followed on these plats is corn, oats, red clover, winter wheat, and alfalfa. During the past 5 years it has been the practice to sow some alfalfa with the red clover and also to sow some hubam sweet clover in with the winter wheat. The alfalfa is allowed to remain on the land for 5 years. Hence, alfalfa and red clover have been grown on these plats frequently and there has been ample opportunity for

the soil of all the plats to become well supplied with the respective root nodule bacteria. The results obtained upon analysis of the soils from one block of plats in this rotation are shown in Table 3. Corn was grown on this land in 1933 previous to taking the first set of samples. The two sets of samples taken in the spring were obtained during the time the land was being prepared for seeding oats and the legume crops.

TABLE 3.—*Numbers of root nodule bacteria per gram of soil in the 5-year rotation plats in the fall of 1933 and spring of 1934.**

Plat No.	Soil treatment	pH	*R. meliloti*			*R. trifolii*		
			Oct. 25	Mar. 20	April 2	Oct. 25	Mar. 20	April 2
1012	Check	5.72	10	10	10	1,000	1,000	10
1013	Manure	5.72	100	100	1,000	1,000	1,000	100
1014	M + lime	6.85	10,000	10,000	100,000	10,000	10,000	100,000
1015	M + L + RP	6.87	100,000	10,000	1,000	10,000	10,000	1,000
1017	Check	5.84	100	100	100	1,000	10,000	100
1019	CR + lime	6.77	10,000	1,000	10,000	10,000	1,000	10,000
1020	CR + L + RP	6.87	10,000	100,000	10,000	10,000	100,000	10,000

*Cropping system: 1930, oats + red clover and alfalfa; 1931, red clover and alfalfa; 1932, wheat + hubam sweet clover; 1933, corn.

These data indicate the large extent to which the numbers of these organisms were increased by the application of manure, limestone, and rock phosphate to this soil. The most striking example is shown on October 25 in the case of *R. meliloti* where the number was increased from 10 per gram in the untreated soil to 100,000 in the soil treated with manure, limestone, and rock phosphate. This is certainly an increase of real significance, and a large influence on the nodulation of a legume crop grown on these soils might be expected. Although the increases in numbers effected by the various soil treatments were not so pronounced or regular at other times, the data as a whole indicate the same general effect. The importance of maintaining the soil in a high state of fertility in order to support a relatively large number of root nodule bacteria in the soil is emphasized.

In Table 4 data obtained in other tests on plats in the 5-year rotation are presented. Corn had been grown on the 1000 series of plats during the season prior to sampling and a year had elapsed since alfalfa and red clover had been grown on the land. Alfalfa had been grown on the 900 series of plats for 5 years and until about a month before the samples were taken. At the time of sampling this series of plats numerous undecayed alfalfa roots were present in the soil.

The data of Table 4 show the same general effects of the various soil treatments on the numbers of alfalfa and red clover root nodule bacteria as were shown by the data from the 2- and 3-year rotation soils and also the other series of soils under the 5-year rotation. An increase in numbers of root nodule bacteria was brought about by each additional soil treatment in most instances. The most striking example of this is shown in the numbers of *R. meliloti* in the soils of the 900 series. In that case there was an increase from 1,000 per gram

of untreated soil to 1,000,000 per gram of the soil treated with manure, limestone, and rock phosphate. The numbers of *R. trifolii* did not appear to be affected differentially by the various soil treatments in the 900 series, but there was a 10-fold increase in each of the treated soils over the untreated soil of the check plat.

TABLE 4.—*Numbers of root nodule bacteria per gram of soil in the 5-year rotation plats.**

Plat No.	Soil treatment	pH	*R. meliloti*	*R. trifolii*
Series 1000, Samples Taken Nov. 9, 1934				
1024	Check	6.22	100	100
1025	Manure	6.41	100	100
1026	M + lime	7.48	1,000	1,000
1027	M + L + RP	7.74	10,000	10,000
1031	CR + L	8.11	1,000	1,000
Series 900, Samples Taken Nov. 14, 1934				
924	Check	5.77	1,000	1,000
925	Manure	5.81	10,000	10,000
926	M + lime	6.73	100,000	10,000
927	M + L + RP	6.81	1,000,000	10,000
931	CR + L	7.34	100,000	10,000

*Cropping systems: Series 1000, 1931, oats + clover and alfalfa; 1932, red clover and alfalfa; 1933, wheat + hubam sweet clover; 1934, corn. Series 900, 1926, corn; 1927, oats; 1928, clover; 1929, wheat; 1930–34, alfalfa. The alfalfa of this series was plowed up within a month prior to sampling.

It may also be observed from the data of Table 4 that there were 10 to 100 times as many alfalfa root nodule bacteria in the soils of the 900 series as in the similarly treated soils of the 1000 series of plats. This undoubtedly was due to the fact that alfalfa was growing on the soils of the 900 series immediately preceding the time of sampling of the soils, whereas it had been over a year since it had been grown on the soils of the 1000 series. It is very likely that soils in the 1000 series had decreased markedly in alfalfa root nodule bacteria since the alfalfa crop had been plowed under. These results agree to a certain extent with the conclusions drawn by Wilson concerning the soybean root nodule bacteria.

It is obvious, from the results previously presented, that the rate of disappearance of these organisms depends largely upon the character of the soil in which they occur. On the other hand, there was a markedly smaller number of these organisms in the soils where alfalfa had not grown for a year, even though the soil was apparently in good condition for the growth of the bacteria. The pH of the soil of plat 1027, for instance, was definitely on the basic side of the optimum, and the soil had also received applications of organic matter and phosphate fertilizer. Obviously, this soil, even with the favorable treatments, was not as suitable a habitat for the organisms in the absence of its symbiont as in its presence.

SUMMARY AND CONCLUSIONS

1. Wilson's modification of the dilution method was used in determining the approximate numbers of *R. meliloti* and *R. trifolii* in variously treated soils at the Agronomy farm at Iowa State College.

2. It was found that, in general, the number of these root nodule bacteria in soils depends upon the previous cropping history of the land, and also upon the fertilizer treatments that have been made to the soil.

3. Larger numbers of both species were found in the soil of the 3-year rotation plats where mixed red clover and alfalfa are grown every third year than in the soil of the 2-year rotation plats where legume crops have not grown for over 20 years.

4. Larger numbers of *R. meliloti* were also present in soil where alfalfa had been plowed up a month previous to sampling than where alfalfa had not been grown on the land for over a year.

5. Applications of crop residues, manure, limestone, and rock phosphate each enabled the soil to support a larger number of alfalfa and red clover root nodule bacteria. The largest numbers of these organisms occurred in soils receiving combinations of these treatments.

6. It appears that the condition of the soil with reference to organic matter, lime, and phosphate has a much larger influence on the numbers of these organisms in this soil than does the frequency of growth of the host plant.

7. It is suggested that recommendations for soil or seed inoculation should be based, not only upon a knowledge of the cropping system to which the soil has been subjected, but also upon a knowledge of the soil management practices that have been followed.

8. As more is learned of the factors affecting the growth of the root nodule bacteria in soils and also of the numbers required in the soil for the maximum benefit to the host, it is entirely possible that the determination of their numbers will serve as a better means for determining the need for inoculation than we now have.

LITERATURE CITED

1. LOCHHEAD, A. G., and THEXTON, R. N. Quantitative studies of three species of Rhizobium in soils of different fertilizer treatment. Jour. Bact., 29 : 77. 1925.
2. STEVENSON, W. H., BROWN, P. E., and FORMAN, L. W. Crop returns under various rotations in the Wisconsin drift soil area. Iowa Agr. Exp. Sta. Bul. 241. 1926.
3. WALKER, R. H., and ERDMAN, L. W. Preliminary note on the sterilization of seeds of the Leguminosae with hydrogen peroxide. Proc. Iowa Acad. Sci., 33 : 91–95. 1926.
4. WILSON, J. K. Effect on nodulation of supplementing the legume bacteria of the soil with artificial cultures. Jour. Amer. Soc. Agron., 18 : 280–294. 1926.
5. ————. Legume bacteria population of the soil. Jour. Amer. Soc. Agron., 18 : 911–919. 1926.
6. ————. Seasonal variation in the number of two species of Rhizobium in soil. Soil Science, 30 : 289–296. 1930.
7. ————. Longevity of *Rhizobium japonicum* in relation to its symbiont on the soil. Cornell Univ. Agr. Exp. Sta. Mem. 162. 1934.

DIVERGENT INFLUENCE OF DEGREE OF BASE SATURATION OF SOILS ON THE AVAILABILITY OF NATIVE, SOLUBLE, AND ROCK PHOSPHATES[1]

R. L. Cook[2]

It is known that the native and soluble phosphates applied as fertilizers, remain more readily available when the pH of the soil is about 6.5 or higher (barring a great excess of $CaCO_3$), and that rock phosphate is usually more effective when the soil is at least slightly acid. In certain cases, lime with rock phosphate has depressed yields as compared to rock phosphate alone, while the opposite result has been obtained with lime and superphosphate. This investigation was undertaken in an attempt to explain more fully the reasons for these divergent effects of base saturation or soil reaction on the ability of plants to obtain phosphorus from different sources.

The influence of base saturation or soil reaction on the availability of native phosphates and applied rock or soluble phosphates has been studied quite extensively, and the following are only a few references to earlier work.

HISTORICAL

Kossowitsch (7)[3] and Prianischnikow (9) showed in pot and field studies that rock phosphate is more effective as a source of phosphorus on acid than on non-acid soils, especially the calcareous ones.

Ford (2), studying the soils of the Kentucky Station experimental fields, found that lime markedly reduced the rate of transformation of the rock phosphate to other forms.

Prianischnikow (8), Truog (12), and others have classified certain plants on the basis of their feeding power for the phosphorus of rock phosphate. Truog suggests that the solution of rock phosphate in the soil through its reaction with carbonic acid should be considered a balanced reaction similar to the following: $Ca_3(PO_4)_2 + 2H_2CO_3 \rightleftharpoons Ca_2H_2(PO_4)_2 + Ca(HCO_3)_2$. Both of the products formed are soluble and, according to the law of mass action and chemical equilibrium, must be removed from solution in proper proportion if the reaction is to continue indefinitely. Truog holds that plants which require large amounts of calcium remove the soluble calcium salts produced in this reaction at a rate sufficiently rapid to allow the solution of the phosphate to continue. As a consequence, they are strong feeders on rock phosphate. Plants which are low in calcium quickly allow an accumulation of $Ca(HCO_3)_2$ to a point of saturation, after which, further solution of the phosphate is very slow. As a consequence, these plants are weak feeders on

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[3]Figures in parenthesis refer to "Literature Cited," p. 311.

rock phosphate. One of the purposes of the present investigation was to ascertain whether or not the removal of calcium from the soil solution through base exchange reactions would make it possible for plants low in calcium to feed effectively on rock phosphate.

For a detailed review of the subject of plant feeding, the reader is referred to Thomas (11).

Teakle (10) showed that with varying degrees of soil acidity different cations are responsible for the removal of phosphate from the soil solution. Ford (3) emphasizes the fact that phosphates fixed as calcium phosphate are readily available while those fixed as ferric phosphate are less available. His work shows that fixation in difficultly soluble form is due to the hydrated iron oxides, such as goethite, which form very difficultly soluble basic iron phosphates.

BASE SATURATION AND AVAILABILITY OF ROCK PHOSPHATE TO PLANTS

The first part of this investigation deals with the influence of hydrogen- and calcium-saturated inorganic and organic base exchange material on the availability of rock and tricalcium phosphate to plants in quartz sand cultures. It was thought that if some hydrogen-saturated exchange material was placed in the system, it would take up the soluble calcium, and thus plants which are weak feeders would be able to obtain phosphorus more advantageously from the rock phosphate.

PREPARATION OF EXCHANGE MATERIAL

From bentonite.—Since, as shown by Kerr (6), bentonite has exchange properties similar to those of soils, work was started with this material which was prepared as follows: The bentonite, pulverized to 40-mesh, was dispersed in a large quantity of water; and after standing over night, the suspension was siphoned off and evaporated to dryness. To remove carbonates, the residue, after pulverizing again to 40-mesh, was digested for 48 to 60 hours in a solution of N $NH_4C_2H_3O_2$ maintained with HNO_3 at a pH of 5.5. The $NH_4C_2H_3O_2$ prevented the material from swelling and becoming difficult to handle. When digestion was complete, the mixture was leached on a Buechner funnel with a solution, 0.5 N with respect to NH_4NO_3, and 0.05 N with respect to HNO_3, until free of calcium, and then with distilled water until deflocculation caused the leaching to become very slow. The dried material was ground to pass a 100-mesh sieve. The product, saturated partly with the H-ion and partly with the NH_4-ion, was placed in shallow nickel pans and heated to 450° C in a muffle furnace for 48 hours. This treatment removed all but traces of the replaceable ammonia, leaving the material saturated with hydrogen. Previous work had shown that heating to 450° C does not alter the exchange capacity of this material. The heating also served to break down any free NH_4NO_3 and volatilize any remaining nitric acid.

Calcium-saturated exchange material from bentonite was prepared by treating material in the manner just described up to the point of heating, when, in place of heating, it was digested over night on the steam plate with a solution 0.5 N with respect to both $(NH_4)_2CO_3$ and $NH_4C_2H_3O_2$, filtered, and washed with 0.5 N $NH_4C_2H_3O_2$ until free of $(NH_4)_2CO_3$. Next it was saturated with calcium by leaching with N $CaCl_2$, and washed with distilled water and then alcohol until free of chlorides. The material was then dried and ground to 100-mesh.

From soils.—Hydrogen-saturated exchange materials from organic and inorganic soils were prepared by leaching the soils with 0.05 N HNO_3 until calcium could no longer be detected in the filtrates. This required from 24 to 48 hours of leaching on a Buechner funnel, using suction only when necessary to maintain a slow rate of leaching. The excess acid was removed by washing with water until the filtrate became cloudy, which condition indicated that enough acid had been removed to allow deflocculation of the colloids. The soil was then dispersed in a large volume of water, and after standing over night, the suspension was siphoned off, evaporated to dryness, and the residue ground to 100-mesh.

The exchange capacity of the materials was determined as follows: A 0.5-gram sample in 200 cc of a solution 0.5 N with respect to both $(NH_4)_2CO_3$ and $NH_4C_2H_3O_2$ was digested on a steam plate for 2 hours. The suspension was then filtered, and the material washed with 0.5 N $NH_4C_2H_3O_2$ until all carbonate was removed. The sample was leached with 300 cc of N $CaCl_2$ and then with alcohol (80% by volume) until free of chlorides. The calcium was then displaced by leaching with 300 cc of N $NH_4C_2H_3O_2$, and determined in the usual way.

PLAN OF POT CULTURES

Oats, corn, millet, and buckwheat were grown in a greenhouse in 2-gallon glazed earthenware jars, each filled with 10 kg of white quartz sand. The jars had holes for drainage. The sand contained 6 p. p. m. of phosphorus soluble in 0.002 N sulfuric acid, and 0.1 millequivalent of calcium as $CaCO_3$ per 100 grams. Phosphates as follows were used: The rock phosphate was 300-mesh material containing 34.53% P_2O_5 and 29.16% calcium. It was applied at the rate of 500 pounds per acre. The soluble phosphate was C. P. monocalcium phosphate, and was applied in an amount equivalent to 500 pounds per acre of 20% superphosphate. The tricalcium phosphate was C. P. material treated to reduce solubility in water by heating to 450° C for 24 hours and then leaching with distilled water until the leachate became practically free of phosphorus. Before this treatment, the material contained considerable water-soluble phosphorus.

All exchange materials and phosphorus-carrying compounds were thoroughly mixed with the dry sand. Enough seeds were planted to permit selection of sturdy, uniformly spaced plants, 3 in the case of corn and 15 of the others. A moisture content of about 10% was maintained. Shortly after the plants appeared above the surface, each pot received the following nutrient salts dissolved in 500 cc of water:

KNO_3	1.0 gram	$MnCl_2$	0.005 gram
$Ca(NO_3)_2 \cdot 4H_2O$	0.5 gram	NaI	0.001 gram
$MgSO_4 \cdot 7H_2O$	0.25 gram	$FeCl_3 \cdot 6H_2O$	0.014 gram

In most cases the crops were harvested after 4 to 6 weeks of growth. One series of oats was allowed to mature. The tissue was placed in paper bags, dried in a steam oven at about 80°C, and then weighed.

YIELDS WITH BENTONITE EXCHANGE MATERIAL

The weights of the various crops produced with and without exchange material from bentonite are given in Table 1.

Oats.—The results show that rock phosphate, without and with calcium-saturated exchange material, produced no larger yields of oats than the controls (no phosphate), but with hydrogen-saturated

TABLE 1.—*The effect of hydrogen- and calcium-saturated exchange material from bentonite on the availability of rock phosphate and tricalcium phosphate as measured by growth of various crops in quartz cultures.*

Phosphate and exchange material additions to cultures*	pH of culture	Yield in grams (average of two pots)														
		Oats					Corn				Millet		Buckwheat			
		Series 1			Series 2		Series 1		Series 2				Series 1		Series 2	
		Grain in tops %	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops
Control, no Phos. or Ex. Ma.	8.0	23.1	1.4	4.4	1.7	3.5	3.5	7.6	2.6	3.9	0.5	0.8	0.8	8.5	1.0	5.9
H. Ex. Ma., 100 grams	6.4	22.6	1.2	4.0	—	—	3.7	6.8	—	—	—	—	1.0	9.7	—	—
Rock Phos.	8.0	29.7	1.2	5.8	1.6	3.9	6.8	16.3	4.1	4.1	0.3	0.8	1.6	12.6	1.3	9.0
Rock Phos. + 100 grams H. Ex. Ma.	6.4	46.3	4.2	20.9	2.5	10.1	9.6	27.4	10.4	26.6	2.9	10.2	0.8	9.5	1.0	9.0
Rock Phos. + 200 grams H. Ex. Ma.	5.8	44.3	3.7	21.0	—	—	—	—	—	—	—	—	—	—	—	—
Rock Phos. + 100 grams Ca. Ex. Ma.	8.0	—	—	—	2.1	3.6	—	—	3.0	5.4	—	—	—	—	—	—
$Ca_3(PO_4)_2$	8.0	—	—	—	—	—	—	—	—	—	—	—	—	—	1.1	9.6
$Ca_3(PO_4)_2$ + 100 grams H. Ex. Ma.	6.4	—	—	—	—	—	—	—	—	—	—	—	—	—	1.2	10.5
$CaH_4(PO_4)_2.H_2O$	8.0	36.9	5.1	21.7	—	—	8.6	25.7	—	—	4.1	11.3	1.7	12.3	1.0	10.9

*H. Ex. Ma. = Hydrogen-saturated exchange material from bentonite; Rock Phos. = Rock phosphate; Ca. Ex. Ma. = Calcium saturated exchange material from bentonite. Phosphate applications on the acre basis were 500 pounds of rock phosphate, an equivalent amount of $Ca_3(PO_4)_2$, and $CaH_4(PO_4)_2.H_2O$ equivalent to 500 pounds of 20% superphosphate. The exchange material varied in exchange capacity from 82 to 100 M. E. per 100 grams.

exchange material from bentonite it produced as well as the soluble phosphate. Increasing the amount of exchange material from 100 to 200 grams per pot produced no additional increases in yield. Fig. 1 shows the growths produced in the first oats series.

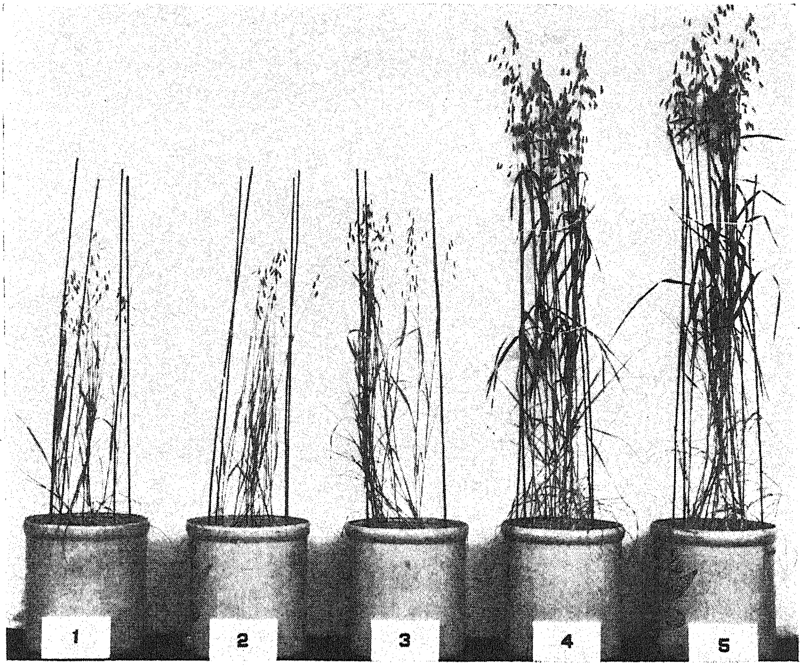

FIG. 1.—The effect of hydrogen-saturated exchange material from bentonite on the availability of rock phosphate to oats.

1, control, no phosphate or exchange material; 2, exchange material, 100 grams per pot; 3, rock phosphate, 500 pounds per acre; 4, rock phosphate, 500 pounds per acre plus exchange material, 100 grams per pot; 5, monocalcium phosphate equivalent to 500 pounds of 20% superphosphate per acre.

It was desired in the case of oats and buckwheat to save the sand for further work, so the roots could not be conveniently washed out, but were screened out after drying, and this caused some loss and inconsistencies in weights.

Buckwheat.—The results show that buckwheat, a crop which, according to Truog (12), contains over six times as much calcium as does oats, can feed almost as well on rock phosphate as upon soluble phosphate, and that, in the first series, instead of increasing the yields, the hydrogen-saturated base exchange material very noticeably depressed them. It was thought that this injurious effect might be due to the liberation of fluorine from the rock phosphate, and in order to test this possibility some of the buckwheat tissue was analyzed for fluorine, giving results as follows:

Phosphate and exchange material additions to cultures	Fluorine in buckwheat tissue %
Control	0.00682
Rock phosphate	0.02270
Rock Phosphate plus 100 grams H-saturated exchange material	0.02150
$CaH_4(PO_4)_2 \cdot H_2O$	0.00319

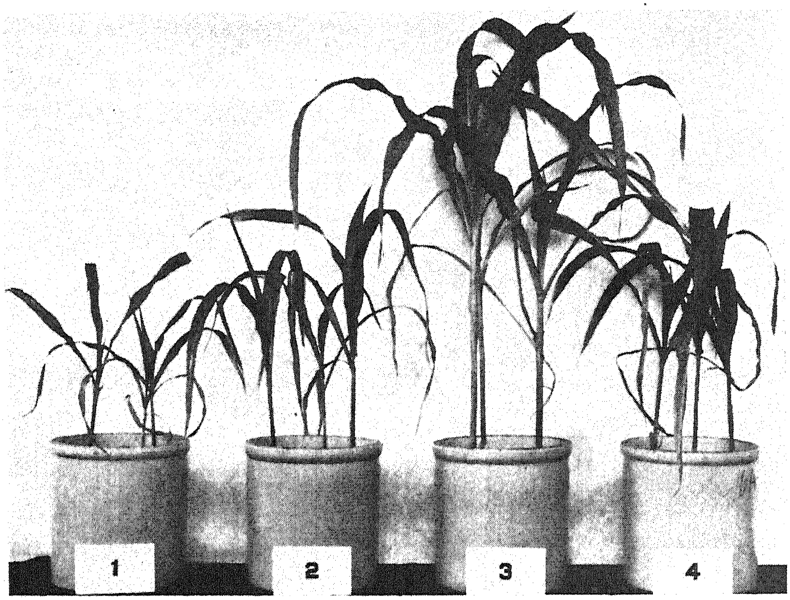

FIG. 2.—The effect of hydrogen- and calcium-saturated exchange material from bentonite on the availability of rock phosphate to corn.

1, control no phosphate or exchange material; 2, rock phosphate, 500 pounds per acre; 3, rock phosphate, 500 pounds per acre, plus hydrogen-saturated exchange material, 100 grams per pot; 4, rock phosphate, 500 pounds per acre, plus calcium-saturated exchange material, 100 grams per pot.

These data show that the plants grown with exchange material contained no more fluorine than those grown without it. Furthermore, in another buckwheat test including both tricalcium and rock phosphate, this deleterious effect was absent, and the exchange material caused slight, although not significant, increases in yield with both forms of phosphate.

Corn.—On the basis of its calcium content and inability to feed on rock phosphate, corn has been placed by Truog (12) in the same class with oats. The results clearly indicate that the availability of the rock phosphate to this crop was greatly raised by the hydrogen-saturated exchange material. Fig. 2 shows the relative growths of the plants in the second series 41 days after planting.

Millet.—The data show millet, which is low in calcium, to be exactly like oats and corn as regards its response to the presence of hydrogen-saturated base exchange material.

ANALYSES OF OATS AND BUCKWHEAT

In order to determine more positively if the influence of base saturation on growth was due to phosphorus availability, chemical analyses were made of oats and buckwheat. The results are presented in Table 2.

Oats.—The data show conclusively that hydrogen-saturated exchange material from bentonite made it possible for oats to absorb much more phosphorus from rock phosphate. In the first series, the plants feeding on rock phosphate without exchange material contained only 1.65 mgm of phosphorus per culture, while those which were treated with rock phosphate and 100 grams of hydrogen-saturated exchange material contained 23.84 mgm per culture, over 14 times as much. On the other hand, the calcium-saturated exchange material lowered the percentage of phosphorus and raised that of calcium in the second oats series. In this same test the exchange material saturated with hydrogen caused the plants to absorb 11.7 times as much phosphorus as from rock phosphate alone and 12.7 times as much as from rock phosphate plus calcium-saturated exchange material.

Buckwheat.—This crop fed very effectively upon rock phosphate alone and the exchange material made little difference in the phosphorus content of the first series but did raise it markedly in the second. In contrast to oats, the buckwheat in the first series absorbed almost normal amounts of phosphorus from rock phosphate alone and was not benefited through the addition of the hydrogen-saturated exchange material.

RESULTS WITH ORGANIC SOIL EXCHANGE MATERIAL

It was deemed advisable to check the preceding results by the use of exchange material from actual soils, both organic and inorganic. Some organic exchange material was separated from a sample of rifle peat according to the methods previously described, and used in pot cultures of corn and millet. The results, presented in Table 3, show that this exchange material has exactly the same influence on the availability of rock phosphate as that from bentonite. When no exchange material was present, these crops were unable to feed effectively on rock phosphate; but with an application of only 10 grams of the hydrogen-saturated exchange material, the rock phosphate became almost as available as the monocalcium phosphate. Fig. 3 shows the appearance of millet 38 days after planting.

The total phosphorus content of the millet reported in Table 3 shows that the increased yields are correlated with an increased availability of the rock phosphate. The plants grown with rock phosphate and 10 grams of exchange material contained almost seven times as much phosphorus as those grown with rock phosphate alone.

TABLE 2.—*The effect of hydrogen- and calcium-saturated exchange material from bentonite on the phosphorus and calcium contents of the oats and buckwheat plants referred to in Table 1; data averages from duplicate pots.*

Phosphate and exchange material additions to cultures*	Phosphorus content									Calcium content of oats		
	Oats					Buckwheat						
	Series 1			Series 2		Series 1		Series 2		Series 1		Series 2
	Straw %	Grain %	Tops total per pot, mgm.	Tops %	Tops total per pot, mgm.	Tops %	Tops total per pot, mgm.	Tops %	Tops total per pot, mgm.	Straw %	Grain %	Tops %
Control, no Phos. or Ex. Ma.	0.010	0.054	0.80	0.042	1.41	0.209	17.76	0.100	5.90	0.452	0.283	0.438
H. Ex. Ma., 100 gm.	0.015	0.128	1.59	—	—	—	—	—	—	0.407	0.280	—
Rock Phos.	0.008	0.078	1.65	0.046	1.77	0.535	67.40	0.344	30.78	0.573	0.157	0.397
Rock Phos. + 100 grams H. Ex. Ma.	0.051	0.188	23.84	0.206	20.70	0.577	54.81	0.612	55.08	0.483	0.175	0.372
Rock Phos. + 200 gm. H. Ex. Ma.	0.079	0.172	25.20	—	—	—	—	—	—	0.316	0.127	—
Rock Phos. + 100 gm. Ca. Ex. Ma.	—	—	—	0.045	1.62	—	—	—	—	—	—	0.442
$CaH_4(PO_4)_2.H_2O$	0.140	0.177	33.30	—	—	0.705	86.70	0.550	59.95	0.591	0.262	—

*See Table 1 for abbreviations.

TABLE 3.—*The effect of hydrogen-saturated exchange material from an organic soil on the availability of rock phosphate to corn and millet in quartz cultures as measured by growth and phosphorus content.*

Phosphate and exchange material additions to cultures*	Reaction of culture, pH	Corn yield (average of two pots)		Millet			
				Yield (average of two pots)		Phosphorus content of tops	
		Roots, grams	Tops, grams	Roots, grams	Tops, grams	%	mgm.
Control, no Phos. or Ex. Ma.†	8.0	4.1	4.7	1.6	1.7	0.087	1.48
Ex. Ma., 5 gm.	6.5	3.6	4.9	1.6	1.6	0.137	2.19
Rock Phos.	8.0	4.5	5.1	1.7	1.9	0.119	2.26
Rock Phos. + 5 gm. Ex. Ma.	6.5	7.7	8.1	2.1	2.6	0.169	4.39
Rock Phos. + 10 gm. Ex. Ma.	6.0	9.6	19.7	4.4	6.9	0.219	15.11
$CaH_4(PO_4)_2.H_2O$	8.0	10.7	24.7	5.7	9.1	0.406	36.95

*Phosphate applications on the acre basis were 500 pounds of rock phosphate and monocalcium phosphate equivalent to 500 pounds of 20% superphosphate. The exchange capacity of the exchange material was 211 M. E. per 100 grams.

†See Table 1 for abbreviations.

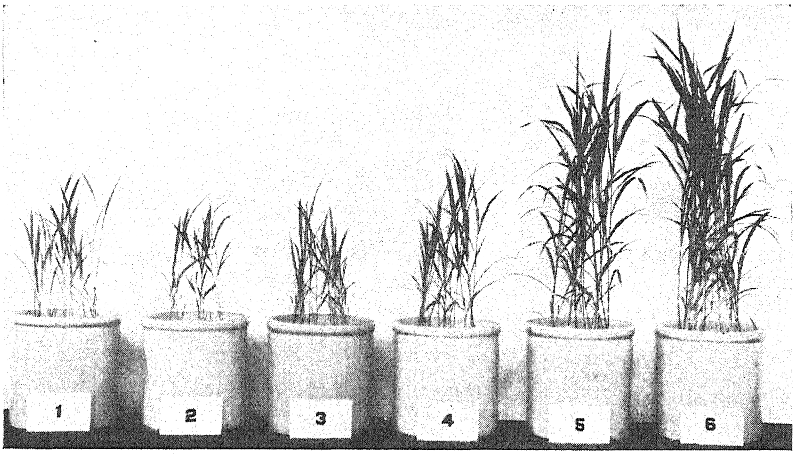

FIG. 3.—The effect of hydrogen-saturated exchange material from an organic soil on the availability of rock phosphate to millet.

1, control, no phosphate or exchange material; 2, exchange material, 5 grams per pot; 3, rock phosphate, 500 pounds per acre; 4, rock phosphate, 500 pounds per acre, plus exchange material, 5 grams per pot; 5, rock phosphate, 500 pounds per acre, plus exchange material, 10 grams per pot; 6, monocalcium phosphate equivalent to 500 pounds of 20% superphosphate per acre.

YIELDS WITH INORGANIC SOIL EXCHANGE MATERIAL

Inorganic soil exchange material was separated in the manner previously described from the subsoil of three Wisconsin soils, Miami silt loam, Superior clay, and Colby silt loam, and used in pot cultures.

The results with millet, recorded in Table 4, show that exchange material from the first two of these soils gave results similar to those obtained with exchange material from bentonite, although the results are not so striking, due, probably in part, to the lower exchange capacity of the material from the soils. The exchange material from the other soil, Colby silt loam, seemed to have a toxic effect both with and without rock phosphate. The leaves of oats turned white soon after germination, and corn and millet plants made less growth than without exchange material. Because the appearance of the plants showed clearly the presence of some extremely toxic substance, the results with material from this soil are not recorded.

TABLE 4.—*The effect of hydrogen-saturated inorganic exchange material from soils on the availability of rock phosphate as measured by growth of millet in quartz cultures.*

Phosphate and exchange material additions to cultures*	Reaction of culture, pH	Yield (average of two pots)	
		Roots, grams	Tops, grams
Control, no Phos. or Ex. Ma.†	8.0	0.50	0.75
Rock Phos.	8.0	0.30	0.80
Rock Phos. + 50 gm. Miami Si. Lo. Ex. Ma.	6.0	0.40	1.25
Rock Phos. + 50 gm. Superior Cl. Ex. Ma.	7.0	0.85	2.25
Rock Phos. + 100 gm. Superior Cl. Ex. Ma.	6.5	1.95	3.75
$CaH_4(PO_4)_2.H_2O$	8.0	4.05	11.25

*The exchange capacity of the Miami silt loam exchange material was 48 M. E. per 100 grams; that of Superior clay 36 M. E. Phosphate applications on the acre basis were 500 pounds of rock phosphate and $CaH_4(PO_4)_2.H_2O$ equivalent to 500 pounds of 20% superphosphate.

†See Table 1 for abbreviations.

Inasmuch as exchange material from bentonite, one organic soil, and two inorganic soils gave similar results with millet, and since millet, corn, and oats reacted in the same way to the influence of exchange material from bentonite, it seems safe to assume that all of these crops would behave similarly with actual soil exchange materials, provided such materials did not contain toxic substances.

DISCUSSION

The data show conclusively that when hydrogen-saturated exchange material is added to sand cultures, rock phosphate is made much more available to certain crops. This fact is manifested by greatly increased growth and amount of phosphorus absorbed. This is in accord with the law of mass action and chemical equilibrium as is also the ineffectiveness of the calcium-saturated exchange material.

The plant roots are continually giving off carbonic acid which reacts with the rock phosphate, producing soluble phosphate and calcium bicarbonate. Both of these products must be removed from solution if the reaction is to continue. Crops such as oats, corn, and millet take up a higher proportion of phosphorus to calcium than exists in rock phosphate. As a result, the calcium bicarbonate gradu-

ally accumulates, equilibrium is established, and the further formation of soluble phosphate is suppressed. The introduction of hydrogen-saturated exchange material into the system provides for the removal of calcium from solution and thus allows the reaction between rock phosphate and carbonic acid to continue and supply the plants with phosphorus. This explains why rock phosphate gives better returns on acid than on calcareous soils.

Plants which use large quantities of calcium feed effectively on rock phosphate because they absorb calcium so rapidly that it does not accumulate as the bicarbonate and slow up the reaction between rock phosphate and carbonic acid. Accordingly, hydrogen-saturated exchange material should be less beneficial to such plants. The results obtained with buckwheat show this to be true.

BASE SATURATION AND AVAILABILITY OF SOIL PHOSPHORUS

The second part of this investigation deals with the effect of increasing the degree of base saturation of 13 Michigan soils by liming on the subsequent availability of the native and applied soluble phosphates. Readily available phosphorus was determined by the Truog (13) method.

TESTS WITH CALCIUM CARBONATE

In the tests with $CaCO_3$, 5 of the 13 soils were used. Large samples (8 kilos) of each soil were weighed out in quadruplicate. Two of the samples were then limed while the other two were not, and one each of the limed and unlimed samples were then phosphated while the other two were left unphosphated. In liming, sufficient 300-mesh calcium carbonate (finely ground limestone) was applied to raise the pH above 6.5, the point above which as shown by Gaarder (4), calcium and magnesium phosphates do not readily decompose. After thoroughly mixing the calcium carbonate with the soils, monocalcium phosphate was applied in solution to the portions to be phosphated, at the rates indicated in Table 5. The rate of application was increased with increasing power of the soils to fix phosphorus in difficultly available forms, as determined by the method outlined by Heck (5). In order to speed up whatever reactions might take place, all cultures during the next 20 days were alternately wetted to optimum moisture and dried at room temperatures 10 times, mixing thoroughly each time. At the end of this period available phosphorus was determined, extreme care being taken to get representative samples. The results are reported in Table 5.

TESTS WITH CALCIUM HYDROXIDE

In the first tests with $Ca(OH)_2$, small samples (0.5 gram of 40-mesh soil) of five soils were weighed out in quadruplicate. Two samples of each soil were limed while two were left unlimed. One of the limed and one of the unlimed samples were phosphated while the other two were not. The samples to be limed were treated with $Ca(OH)_2$ as lime water at the rate of 10 tons per acre. Unlimed samples were treated with an equal volume of distilled water. After standing over

night the samples were dried on a steam plate. Phosphorus as phosphoric acid was then applied to the portions to be phosphated. The results are reported in Table 5.

TABLE 5.—*The influence of additions of $CaCO_3$ and $Ca(OH)_2$ to Michigan soils on the availability of native phosphorus and that applied as monocalcium phosphate and phosphoric acid.*

Type of soil	Tons per acre of lime applied to limed portions	Pounds per acre of phosphorus applied to phosphated portions	Reaction of soil, pH		Pounds of available phosphorus per acre in soils			
					Unphosphated		Phosphated	
			Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
8-kg Samples Treated with $CaCO_3$, Wetted and Dried 10 Times During 20 Days								
Coloma sand....	2	43.5	6.30	7.5	41.6	49.6	58.8	64.8
Fox sandy loam.	4	43.5	5.50	7.2	30.0	40.0	44.0	54.4
Fox sandy loam.	5	87.0	4.30	6.8	35.6	41.0	81.6	97.0
Miami silt loam.	4	43.5	5.50	7.3	19.2	20.0	24.0	34.0
Miami silt loam.	5	108.7	5.80	6.8	19.0	—*	53.0	60.0
0.5-gram Samples Treated with $Ca(OH)_2$ Solution and Dried								
Miami silt loam.	10	800	4.83	—*	69.2	100.4	504.0	710.0
Miami loam....	10	800	5.17	—	64.0	89.2	412.0	684.0
Napanee silt loam........	10	800	5.41	—	43.8	57.0	400.0	634.0
Ontonagon clay loam........	10	800	5.17	—	59.2	69.4	386.0	592.0
Saugatuck fine sand.........	10	800	5.13	—	39.0	40.4	240.0	376.0

*Not determined.

In a further test with $Ca(OH)_2$ conducted to determine the effect of varying degrees of base (calcium) saturation on the power of a soil to fix soluble phosphate in difficultly available form, four 0.5-gram samples of each of eight soils were placed in separate flasks. One sample in each case was wetted with distilled water and the other three with equal volumes of lime water of such concentration as to give applications of 6, 10, and 20 tons of $Ca(OH)_2$ per acre, respectively. After standing over night, the samples were dried on a steam plate. The power of soil, thus treated, to change soluble phosphates to a difficultly available form was then determined as before (5). The phosphorus recovered was taken as a measure of that not fixed and the results are given in Table 6.

DISCUSSION OF RESULTS

The results presented in Table 5 show that in 7 of the 10 acid soils ranging from pH 4.83 to pH 6.30 lime significantly increased the availability of soil phosphates, while in two cases it caused only slight increases. The average available phosphorus content of the seven soils when limed was 63.8 pounds per acre and when unlimed 48.9 pounds per acre.

When soluble phosphorus was applied to these soils, the results were similar. In the case of the five soils to which $CaCO_3$ was added, the lime caused an average increase of 9.7 pounds of available phosphorus per acre. The tests with $Ca(OH)_2$, in which the phosphorus and lime applications were excessive, gave much more outstanding results, the average amount of available phosphorus in the soils after the 800-pound application being when limed, 599.2 pounds per acre, and when unlimed, 388.4 pounds, an average increase of 210.8 pounds per acre.

TABLE 6.—*The influence of increasing additions of $Ca(OH)_2$ (base saturation) to eight Michigan soils on the quantity of phosphorus remaining in readily available form after an addition of 800 pounds per acre of phosphorus applied as H_3PO_4.*

Type of soil	pH of unlimed soil	Pounds available phosphorus per acre in samples which were phosphated after the $Ca(OH)_2$ additions indicated			
		No $Ca(OH)_2$	6 tons $Ca(OH)_2$	10 tons $Ca(OH)_2$	20 tons $Ca(OH)_2$
		Acid Soils			
Miami silt loam....	4.83	504	598	710	740
Miami loam.......	5.17	412	572	684	658
Napanee silt loam...	5.41	400	526	634	628
Ontonagon clay loam	5.17	386	496	592	592
Saugatuck fine sand.	5.13	240	372	376	452
		Non-acid Soils			
Brookston clay loam.	7.20	668	676	730	—*
Wauseon loamy sand	7.28	820	854	842	—
Wisner silt loam....	8.00	790	800	800	—

*Not determined.

The data given in Table 6 show the effect of degree of base saturation on the power of eight soils to fix phosphorus in a difficultly available form. With the five acid soils, increased applications of $Ca(OH)_2$ resulted in consistent and significant increases in the amounts of phosphorus which remained in the soils in easily available form after the standard 800-pound application. With the three non-acid soils, applications of lime increased only slightly the amounts of phosphorus which remained available, the greatest increase being 62 pounds in the case of the 10-ton application to the Brookston soil, while with the acid soils the average increase for that application was 210.8 pounds.

It is apparent that increased base saturation and consequent decrease in acidity play an important rôle in increasing the availability of soil phosphorus. Ford (2) reported similar results when soluble phosphate was applied to field plats.

When soluble phosphates are applied to a neutral or calcareous soil, there is an immediate reaction with the active calcium or magnesium which is plentiful in such a soil, and the resulting calcium or

magnesium phosphates remain as stable compounds easily available to plants, excepting in some cases when the amount of calcium carbonate becomes excessive (more than 2 or 3%). In the case of soils with a pH appreciably below 6.5, the calcium and magnesium phosphates dissolve sufficiently so that when they come in contact with hydrated iron oxides, a reaction takes place and basic iron phosphates are formed, which Dean (1) and Ford (3) report as being very similar to dufrenite, the phosphorus of which is but slowly available to plants.

SUMMARY

The influence of hydrogen- and calcium-saturated exchange material separated from bentonite, peat, and mineral soils on the availability of rock phosphate to oats, corn, millet, and buckwheat grown in quartz cultures was investigated. The influence of degree of base (calcium) saturation on the availability of native and applied soluble phosphates in 13 Michigan soils was also studied in the laboratory. It is concluded as follows:

1. The addition of hydrogen-saturated exchange material from bentonite and organic and inorganic soils greatly increased the availability of rock phosphate to crops like oats, millet, and corn which otherwise do not feed well on it. This was evidenced by increased yields and a higher phosphorus and a lower calcium content of the plants. Calcium-saturated exchange material from bentonite was not beneficial in this way.

2. Hydrogen-saturated exchange material from bentonite did not nearly so markedly affect the availability of rock phosphate to buckwheat, a crop which takes up large quantities of calcium and normally feeds well on rock phosphate.

3. It is concluded that, in accordance with the law of mass action, hydrogen-saturated exchange material greatly increases the availability of rock phosphate to crops low in calcium, such as oats, corn, and millet, but not, generally, to crops high in calcium, such as buckwheat.

4. Increase in base saturation through the application of lime to seven soils resulted over a period of 1 to 20 days in significant increases in amounts of readily available soil phosphates. In two other soils there were slight increases. With the same soils, lime helped to preserve the availability of added soluble phosphates.

5. Increasing additions of lime to five acid soils consistently lowered the power of these soils to fix added soluble phosphate in a difficultly soluble form.

6. The results support the contention that an increase in base saturation of soils lowers the immediate availability of rock phosphate to crops like corn and oats but, on the other hand, tends to keep native soil phosphates and those added as soluble salts in the form of calcium phosphate rather than the less available basic iron phosphates.

LITERATURE CITED

1. DEAN, L. A. Electrodialysis as a means of studying the nature of soil phosphates. Soil Science, 37 : 267–287. 1934.
2. FORD, M. C. The distribution, availability, and nature of the phosphates in certain Kentucky soils. Jour. Amer. Soc. Agron., 24 : 395–410. 1934.
3. ————. The nature of phosphate fixation in soils. Jour. Amer. Soc. Agron., 25 : 134–144. 1933.
4. GAARDER, TORBJORN. Die Bindung der Phosphorsaure in Erdboden. Meddeleke Nr. 14 Fra Vestlandets Forstlige Forsoksstation. 1930.
5. HECK, A. F. A method for the determination of the capacity of a soil to fix phosphorus in difficulty available form. Soil Science, 37 : 343–355. 1934.
6. KERR, H. W. The identification and composition of the soil alumino-silicate active in base exchange and soil acidity. Soil Science, 26 : 385–398. 1928.
7. KOSSOWITSCH, P. Pflanze, Phosphorit, und Boden nach Versuchen des Landwirtschaftlichen chemischen Laboratoriums zu St. Petersburg. Russ. Jr. Expt. Landw., 10 : 839–842. 1909.
8. PRIANISCHNIKOW, D. Zur Frage uber den relativen Wert von verschiedenen Phosphaten. Landw. Vers. Sta., 56 : 107–140. 1902.
9. ————. Uber den Einfluss von Kohlensauren Kalk auf die Wirkung von verschiedenen Phosphaten. Landw. Vers. Sta., 75 : 357–376. 1911.
10. TEAKLE, L. J. H. Phosphate in the soil solution as affected by reaction and cation concentrations. Soil Science, 25 : 143–162. 1928.
11. THOMAS, WALTER. The feeding power of plants. Plant Phys., 5 : 443–489. 1930.
12. TRUOG, E. The utilization of phosphates by agricultural crops, including a new theory regarding the feeding power of plants. Wis. Agr. Exp. Sta. Res. Bul. 41. 1916.
13. ————. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22 : 874–882. 1930.

A METHOD FOR REMOVING AND DETERMINING THE FREE IRON OXIDE IN SOIL COLLOIDS[1]

M. DROSDOFF AND E. TRUOG[2]

FREE ferric oxide, hydrated and unhydrated, is found in all soils and often makes up a considerable portion of the inorganic colloid fraction of soils. This iron oxide is intimately mixed with the other soil colloids and sticks so tenaciously to the surface of the larger mineral particles that when an attempt is made to separate, mechanically, the colloid fraction from the rest of the soil, much of the iron oxide as well as other colloids are left sticking on these surfaces. Frequently the occasion arises in soil investigations when it would be desirable to remove and determine the free iron oxide in soil colloids. Attempts to do this have not been entirely satisfactory. For this purpose, hydrochloric and oxalic acids have usually been used, but since they also dissolve silicate iron as well as other constituents to a marked extent, their use has not met with general favor. Appreciable amounts of ferrous oxide may be present in poorly aerated soils, but since its solution and removal present no special difficulties, its consideration is dispensed with here.

In working on this problem, the writers were using sodium acid oxalate as the solvent, and in an attempt to speed up the solution of the free iron oxide and thus lessen the time of extraction and hence solution of other constituents, the writers were prompted to introduce hydrogen sulfide into the system, thinking its action might aid in the solution. The action of the hydrogen sulfide was far beyond expectation. It seemed to act on the free ferric oxide without the iron oxide having to go into solution. In another test, the acid oxalate was omitted and the iron oxide was quickly changed to the black sulfides.

In looking up the literature regarding this subject, it was found that hydrated ferric oxide has been used for more than 60 years as an absorbent for H_2S in the purification of coal gas. Wright (4)[3] in 1883 reported that $Fe(OH)_3$ suspended in water turned black when H_2S was introduced, the products formed being a mixture of Fe_2S_3, FeS, and S. Allen, *et. al.* (1) showed that the black iron sulfides produced in the reaction were completely soluble in cold dilute HCl. Recently, Pearson and Robinson (3) summarized the literature on the subject and concluded that a mixture of sulfides is formed.

ACTION OF HYDROGEN SULFIDE ON IRON OXIDE

Preliminary tests with H_2S-saturated water suspensions of 100-mesh limonite showed rapid formation of black iron sulfides which dissolved readily in cold 0.05 N HCl. Most of the original iron oxide was

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[3]Figures in parenthesis refer to "Literature Cited," p. 317.

dissolved by this treatment. To determine whether or not the acidity of the H_2S solution (about pH 4) dissolved the iron oxide before it was changed to sulfides, the H_2S solution was neutralized with NH_4OH before being used. This neutralized H_2S solution was even more effective than the acid H_2S solution, which indicated that the sulfides are formed directly as a result of a surface reaction.

In further tests, samples (50 mg each) of finely powdered limonite and hematite were shaken with 200 cc of H_2S-saturated water adjusted to pH 7 with NH_4OH. The iron sulfides formed were dissolved in 0.05 N HCl and the iron in solution determined. Shaking for ½ hour with subsequent HCl treatment dissolved 90% of the limonite but only 8.5% of the hematite. After 1 hour of shaking, all of the limonite dissolved but only 9% of the hematite, indicating that the amount of surface exposed by the crystalline hematite was not sufficient for rapid action of the H_2S.

Samples of crystalline hematite and goethite and ordinary limonite were then prepared in which the particle size was 0.0001 mm and less in diameter. The goethite and hematite were ground in a tool steel ball mill. Suspensions containing 50 mg of these materials in 200 cc of H_2S-saturated water adjusted to pH 7 with NH_4OH were shaken for ½ hour. The iron sulfides formed were dissolved in cold 0.05 N HCl, the solution filtered, and the iron determined in the filtrate. In the case of goethite and limonite all of the material had dissolved, but in the case of the hematite 7% of the sample remained undissolved. Upon analysis, 40% of this residue was found to consist of SiO_2, indicating the presence of an iron silicate, the iron of which did not react readily with the H_2S. These tests show that iron oxide, hydrated and unhydrated, when sufficiently finely divided reacts quickly with H_2S to form sulfides which are readily soluble in 0.05 N HCl.

ACTION OF HYDROGEN SULFIDE ON ROCKS AND MINERALS

In order to find out if the H_2S treatment would have an appreciable effect on ferric iron as found in igneous rocks and especially in silicate form, 0.1-gram samples of biotite and basalt and a 0.2-gram sample of granite, all ground finer than 100-mesh, were shaken for several hours with 300 cc of H_2S-saturated water solution adjusted to pH 7 with NH_4OH. At various intervals, 10-cc portions of the suspensions were removed and treated with 10 cc of 0.05 N HCl and then filtered quickly. After expelling the H_2S and oxidizing with ammonium persulfate, the filtrates were tested for iron colorimetrically with KCNS. Check samples of the mineral powders were treated with water alone instead of the H_2S solution. Samples of these suspensions were treated with HCl, filtered, and tested in exactly the same way as the others. It was found that the H_2S-treated samples gave only a slight test for iron, the same as the check samples, indicating that what little solution of iron took place was due to the direct action of the HCl on the original minerals and that the H_2S treatment does not readily affect iron in the silicate form.

ACTION OF HYDROGEN SULFIDE ON SOIL COLLOIDS AND BENTONITES

A suspension of an Hawaiian lateritic colloid turned black almost immediately when saturated with H_2S and neutralized with NH_4OH. This indicated the presence of a large amount of free iron oxide. The black sulfides formed were easily dissolved in 0.05 N HCl. A suspension of colloid separated from Colby silt loam subsoil and known to contain free iron oxide also turned black quickly when treated with H_2S and neutralized with NH_4OH. On the other hand, a light yellow colloidal suspension separated from Vesper silt loam subsoil was unaffected upon treatment with H_2S, although total analysis showed it to contain several per cent of iron. This iron, since it does not color the colloid yellow or react with H_2S, is not in the free oxide form and may be assumed to exist as a silicate.

To determine whether or not the H_2S treatment affects the base exchange material, 0.3-gram samples of colloid from Colby and Vesper silt loam subsoils and from a yellow bentonite were shaken for 2 hours with 300 cc of neutral H_2S-saturated water solution. Thereafter, 0.1 N HCl was added with stirring until the black sulfides dissolved, when the suspensions were warmed on the steam bath to drive off most of the H_2S and coagulate the colloid. The material was transferred to centrifuge tubes and washed as follows by decantation using the centrifuge: First, twice with 0.05 N HCl to remove all soluble iron; then, twice with 95% C_2H_5OH to remove water which would interfere with the CS_2 treatment[4]; next, three times with a solution consisting of 1 volume of CS_2 and 2 volumes of 95% C_2H_5OH to remove free sulfur; and finally, four to five times with 95% C_2H_5OH to remove the CS_2 that was retained.

After this treatment, the base exchange capacity was determined as follows: The exchangeable hydrogen was displaced by digesting the colloid on the steam bath for several hours with neutral N $NH_4C_2H_3O_2$ solution and washing twice by decantation with the same solution using the centrifuge. Similarly, the colloid was washed five times with neutral N $CaCl_2$ solution to saturate it with calcium, then with 85% C_2H_5OH until free of chlorides, and finally five times with neutral N $NH_4C_2H_3O_2$ solution to replace the exchangeable calcium which was determined in the filtrate. The exchange capacities before and after treatment with H_2S are given in Table 1.

TABLE 1.—*Exchange capacities of soil and bentonite colloids before and after treatment with H_2S.*

Source of colloid	Base exchange capacity, M. E. per 100 grams	
	Untreated	H_2S treated
Colby silt loam subsoil	90	94
Vesper silt loam subsoil	62	60
Yellow bentonite	126	130

[4]In this paper, all percentages of alcohol are given on the volume basis.

The results in Table 1 show that treatment with H_2S solution does not affect the base exchange capacity, and hence it may be assumed that the exchange compound is unaffected. Further evidence of this is the fact that the H_2S extracts contained only traces of alumina and silica, showing that the action on the silicates was negligible.

For determining the length and kind of treatment most efficient in removing the free iron oxide from soil colloids, samples of colloid separated from Superior clay loam subsoil were shaken with various H_2S solutions for different lengths of time, and then acidified with 0.1 N HCl and the amounts of Fe_2O_3 made soluble determined. The results are given in Table 2.

TABLE 2.—*Percentages of iron oxide in Superior clay loam colloid made easily soluble by different H_2S treatments.*

Nature of H_2S solution	Percentages of iron oxide made soluble and extracted	
	½ hr. shaking	1½ hr. shaking
Saturated water solution of H_2S.............	5.7	6.8
Saturated 0.05 *N* HCl solution of H_2S........	5.8	6.9
Saturated water solution of H_2S neutralized with NH_4OH...........................	6.8	6.8
Saturated water solution of H_2S with excess NH_4OH..............................	6.8	6.7

The data for the ½ hour shaking show that saturated H_2S solution neutralized or made alkaline with NH_4OH is more effective than H_2S solution alone, or that acidified with HCl. At the end of 1½ hours the percentages of iron oxide extracted were practically the same in all cases. A neutral solution of H_2S appears to be best both from the standpoint of rapidity of change of Fe_2O_3 to sulfides and least likelihood of attack of other constituents.

PROCEDURE FOR REMOVING AND DETERMINING THE FREE IRON OXIDE IN SOIL COLLOIDS

After separation of colloid from soil.—Separate the soil colloid from the soil by means of any of the common methods and then suspend a sample (0.3 gram is convenient) of the colloid in 250 cc of water and saturate the suspension with H_2S. Neutralize or make slightly alkaline with NH_4OH (requires about 5 cc of N NH_4OH). Shake for ½ hour, acidify with 0.1 N HCl, adding an excess of about 50 cc to dissolve the iron sulfides completely, and then warm on a steam bath to drive off the H_2S and coagulate the colloid. Transfer the suspension to centrifuge tubes and collect the supernatant liquid by decanting after centrifuging. Wash four times with 0.05 N HCl by decantation after centrifuging. Combine the supernatant liquid and washings and determine the iron therein by any standard method.

In case the soil colloid after removal of the free iron oxide is to be used for other purposes, the free sulfur may be washed out as follows, using a centrifuge: Wash twice with 95% C_2H_5OH, then three times

with a CS_2 solution (1 volume of CS_2 to 2 volumes of 95% C_2H_5OH), and finally four to five times with 95% C_2H_5OH. The colloid should now be free of the sulfur that was introduced.

Table 3 gives the amounts of iron oxide removed by the method outlined from some soil and bentonite colloids, together with the total amounts found by analysis of the untreated samples, and also combined or silicate iron obtained by difference. As is to be expected, the amount of free iron oxide is high in the lateritic soil colloid. It is interesting to note that the combined or silicate iron oxide is higher than the free iron oxide in the Wisconsin soil colloids and that the Vesper silt loam and bentonite colloids contain no free iron oxide.

TABLE 3.—*Free iron oxide, total iron oxide, and combined iron oxide in soil and bentonite colloids.*

Source of colloid	Percentages of Fe_2O_3		
	Free oxide by H_2S treatment	Total oxide by total analysis	Combined oxide by difference
Hawaiian lateritic soil	26.7	35.7	9.0
Colby silt loam subsoil	3.5	14.7	11.2
Vesper silt loam subsoil	——	6.2	6.2
Superior clay loam subsoil	6.5	15.7	9.2
Yellow bentonite	——	4.8	4.8
White bentonite	——	6.3	6.3

Without separation of the colloid from the soil.—The occasion may arise in mechanical analysis, specific gravity separations, petrographic work, and phosphate fixation studies when it is desirable to remove the iron oxide directly from the soil. To do this, treat a 5-gram sample of the soil with a 2% solution of Na_2CO_3 on the steam bath for several hours to dissolve colloidal silica and most of the organic matter. Transfer the material to centrifuge tubes, wash twice with 0.05 N HCl by decanting after centrifuging, and then disperse for 1 hour with a dispersion apparatus arranged as suggested by Bouyoucos (2), but having a paddle wheel made of tool steel and a Pyrex glass cup or jar fitted with Pyrex glass rods so as to avoid contamination with nickel and copper. Transfer the suspension, which should have a volume of about 300 cc, to a 500-cc Erlenmeyer flask, saturate with H_2S, make neutral or slightly alkaline with NH_4OH, and proceed from here on as with the separated soil colloid. Soils containing large amounts of free iron oxide may require more than one treatment for complete removal.

SUMMARY

It was found that the free ferric oxide (hydrated and unhydrated) in soil colloids may be easily separated and determined if the suspension of the colloid is first treated for about ½ hour with H_2S. The H_2S quickly changes the free ferric oxide by surface action to iron sulfides which are easily soluble in dilute acid and may thus be extracted and determined. Combined or silicate iron is unaffected in the limited time required as are also other constituents and the base

exchange capacity. It was found that the amount of free ferric oxide in a lateritic soil colloid was high; in colloids from several Wisconsin soils it was less than the combined or silicate iron; and in one soil colloid and two bentonite colloids it was absent, while the combined iron oxide ranged from 4.8 to 6.3%. Free colloidal iron oxide may be removed directly from a soil without previous separation of the colloid as a whole. This is useful in mechanical analysis including specific gravity separations, petrographic work, and phosphate fixation studies.

LITERATURE CITED

1. ALLEN, E. T., CRENSHAW, J. L., JOHNSTON, J., and LARSEN, E. S. Mineral sulfides of iron. Amer. Jour. Sci., 33 : 169–236. 1912.
2. BOUYOUCOS, G. J. The hydrometer as a new and rapid method for determining the colloidal content of soils. Soil Science, 23 : 319–331. 1927.
3. PEARSON, T. G., and ROBINSON, P. L. The reaction between monohydrated ferric oxide and hydrogen sulfide at 100°. Jour. Chem. Soc., 1928, Pt. 1 : 814–823. 1928.
4. WRIGHT, L. T. Some notes on hydrated ferric oxide and its behavior with hydrogen sulfide. Jour. Chem. Soc., 43T : 156–163. 1883.

NOTES

THE INTRODUCTION OF VARIETIES OF FIELD CROPS FREE OF DETECTABLE MIXTURES OR SEGREGATIONS

MODERN methods of plant breeding require the growing of a tremendous number of field plants in small areas. Strains with different morphological characters are often grown in adjoining plats. These conditions give ample opportunity for the cross fertilization and the mechanical mixing of types to take place at some time during the testing of a strain or variety. Mechanical equipment with which varieties and strains are handled also gives further opportunity for mixing.

A strain that is developed by an experiment station and eventually found worthy of introduction has been exposed to these conditions. No matter how carefully the material has been handled there is always the possibility that a trace of off-type plants will appear in commercial fields grown from increases of such introductions. A plan is now followed by the Farm Crops Department at the Michigan Agricultural Experiment Station that should reduce to a minimum the possibility of introducing varieties having any detectable mixtures or segregations.

Roguing of plats and cleaning of equipment is carefully executed with all material. Once the strains from the breeding plats have been reduced to one or two considered worthy to be placed in over-state trials, a large number of selections is made from each of them. Seed from these is planted in progeny head or plant rows. Each progeny is carefully examined in the field and the laboratory for any indications of mixture or segregation. Seed of plants from rows judged to be pure is grouped by progenies and planted a second year and the examination process is repeated. This prevents the overlooking of any segregations that depend on several factor differences for their expression. Any progeny showing segregation in the field is discarded before blooming time whenever the character appears in time.

After this rigid test, all progenies having external characters judged to be morphologically alike are grouped into one population and the seed used as foundation stock. The method is followed with wheat, oats, barley, and beans.—E. E. DOWN, *Michigan Agricultural Experiment Station, East Lansing, Mich.*

BEAN HYBRIDIZATION

THE hybridization of beans presents problems not encountered in the crossing of other field crops. Nearly all workers who have attempted to make bean crosses have found that artificial pollinations made under field conditions generally are unsuccessful. Field pollinations are successful in Michigan when cool weather prevails during the blooming period, but this condition occurs so seldom that all bean hybridization work is carried on in the greenhouse.

The points considered essential for the successful hybridizing of beans in the greenhouse as followed at the Michigan Agricultural

Experiment Station are briefly outlined, except for certain details of emasculation and pollination that are well known by all plant breeders. These points are as follows:

1. The temperature of the greenhouse at pollinating time is maintained above 68°F and below 75°F, if possible.

2. The relative humidity is kept very high by having all walks and soil under benches well watered.

3. The emasculation is done one to two days before the flowers normally shed their pollen and is followed immediately by pollination.

4. The pollination, made on any particular day, is accomplished by removing a pollen-covered stigma from a flower that has opened during the early morning and rubbing it over the surface of the stigma of an emasculated flower. The stigma is used because this is the easiest way of obtaining a quantity of viable pollen. Unless pollen-bearing flowers are very scarce, only one pollination is made with a stigma.

5. Care is taken to prevent mutilation of the flower parts of the emasculated flowers as this would tend to cause their drying out and decrease the possibility of the pollen functioning.

By strictly observing these few points, artificial pollination in 55 to 65% of the cases results in the formation of a pod containing from two to five, or even six, hybrid beans.—E. E. Down. *Michigan Agricultural Experiment Station, East Lansing, Mich.*

AN IMPROVEMENT IN THE HYDROMETER METHOD FOR MAKING MECHANICAL ANALYSES OF SOILS

MOST soils containing appreciable quantities of organic matter produce a froth during the shaking preparatory to taking the hydrometer reading after dispersion of the soil in the special stirring machine. This froth rises to the top of the suspension column and because of its slow disappearance makes a hydrometer reading for total sands at the end of 40 seconds very difficult. The procedure heretofore employed to overcome this difficulty consisted in blowing at the froth. This scheme, however, has not operated successfully, for the froth does not entirely disappear at blowing; and in many cases, the hydrometer reading at the end of 40 seconds cannot be taken accurately.

In experimenting with various means to eliminate this froth difficulty, it was found that the addition of a drop of ether or any of the heavier alcohols, but especially amyl, would cause the froth to disappear almost instantly, leaving a clean surface on the top of the soil suspension, so that a clear and accurate hydrometer reading could easily be taken at the end of 40 seconds. At the same time, the addition of a drop of these heavy alcohols or ether has no other effect upon the soil suspension than that of breaking up the froth.

It is advisable, therefore, to add a drop or two of amyl alcohol or ether to all soils containing organic matter whose combined sand is to be determined by the hydrometer method. The best time to add the amyl alcohol or ether is when the cylinder containing the dispersed

and shaken suspension is placed on the table preparatory to taking the hydrometer reading at the end of 40 seconds. The drop of alcohol or ether is placed on the froth, which disappears instantly, and the hydrometer is then immediately inserted into the suspension column and the reading taken at the end of 40 seconds.—GEORGE J. BOUYOUCOS, *Michigan State College, East Lansing, Mich.*

BOOK REVIEW

AN ANNOTATED BIBLIOGRAPHY OF THE LOW TEMPERATURE RELATION OF PLANTS

By Rodney Beecher Harvey. Minneapolis: Burgess Pub. Co. II + 223 pages; mineographed, fabroid cover. 1935. $4.

THE 3,412 citations are arranged alphabetically by authors and by subjects. Included are references not only to scientific publications, both foreign and American, but also to agricultural periodicals. Since the winter of 1933–34 was one of severe cold in eastern America, it is gratifying to find 1934 references included in the list.

This publication will be found invaluable to the student of winter injury and low temperature effects upon plants in general; while to the practical worker who is called upon to answer questions in this field, the references to observations and practical experience, many of them anonymous, as recorded in agricultural periodicals will be especially useful. (H. B. T.)

AGRONOMIC AFFAIRS

ORGANIZATION OF THE AMERICAN SECTION OF THE INTERNATIONAL SOCIETY OF SOIL SCIENCE

AT a special called meeting held directly following the banquet of the American Society of Agronomy in Washington on the evening of November 22, 1934, an American Section of the International Society of Soil Science was organized. The Committee which had been appointed earlier in the day reported the following brief constitution which was unanimously adopted.

CONSTITUTION
FOR THE AMERICAN SECTION,
INTERNATIONAL SOCIETY OF SOIL SCIENCE

(Adopted November 22, 1934, at Washington, D. C.)

1. The *American Section of the International Society of Soil Science* shall be composed of those members in good standing in the International Society of Soil Science.

2. *Purpose:* The purpose of the Section will be to serve as a medium of expression for the American Members of the International Society, and as an organization through which these members can transact necessary business.

3. *Officers:* The officers shall be a President, Vice-President and a Secretary-Treasurer. They shall be elected at the annual meeting and shall serve for terms of one year, or until their successors are elected and assume office. The officers shall constitute the Executive Committee.

4. *Duties:* The duties of the officers shall be those that usually pertain to the respective offices. The duties of the Executive Committee shall be to determine policies and programs for the Section, and present their findings at the annual meetings for ratification or rejection. Between meetings of the Society, the Executive Committee shall act for the Society in matters of business.

5. *Meetings:* A business meeting shall be held annually, at such time and place as may be designated by the Section; or in case of no decision by the Section, on call of the Executive Committee.

6. *Dues:* Dues of the International Society of Soil Science are set by that body and are payable to the officers designated by that body. Dues in the American Section of the International Society shall be fifty cents per year. Annual dues may be waived or omitted for any year by decision of the Executive Committee if, in their judgment, the treasury has sufficient funds to carry on the functions of the Society without payment of dues.

Immediately following the adoption of the constitution, the following officers were elected: W. P. Kelley, California, *President;* G. W.

Conrey, Ohio, *Vice-President;* and A. G. McCall, Washington, D. C., *Secretary-Treasurer.*

Following the election of officers, S. A. Waksman of New Jersey and M. F. Morgan of Connecticut were selected to constitute a committee on arrangements for those who may be attending the International Congress of Soil Science to be held at Oxford, England, July 30 to August 7, 1935.

Members of the International Society of Soil Science are urged to affiliate with the American Section by sending their application and dues to the Secretary-Treasurer, Doctor A. G. McCall, Bureau of Chemistry and Soils, Washington, D. C.

THIRD INTERNATIONAL CONGRESS OF SOIL SCIENCE

THE Third International Congress of Soil Science will be held in Oxford, on July 30 to August 7, 1935, under the Presidency of Sir John Russell, Director of the Rothamsted Experimental Station, England. The two previous congresses of the series were held in Washington in 1927, and in Leningrad and Moscow in 1930, and were notable for the exceptionally international character of the personnel and the discussions.

The forthcoming Congress will meet as a whole in six plenary sessions at which a general survey of recent advances in every branch of soil science will be made, and it will also work in sections of commissions dealing specifically with (1) soil physics, (2) soil chemistry, (3) soil microbiology, (4) soil fertility, (5) soil classification, and (6) soil technology. Three sub-commissions will discuss problems relating to alkali, forest and peat soils.

A 16-day excursion round Great Britain, leaving Oxford immediately after the Congress and terminating in Cambridge on August 23, has also been arranged for the benefit of members wishing to obtain firsthand knowledge of British agriculture and soils. Every member of the Congress will receive a copy of the official transactions, including the full text of papers read at the plenary sessions and detailed reports of the discussions at the Commission sessions. The cost of the transactions will be included in the Congress fee ($10), payment of which will also entitle members to attend all meetings, receptions, etc., held in connection with the Congress. College accommodation during the Congress can be reserved through the Organizing Committee. Those who are planning to take part in the excursion must deposit a registration fee of $10 before June 30. Intimation of attendance at the Congress should be sent as soon as possible to the Secretary of the Organizing Committee, G. V. Jacks, Imperial Bureau of Soil Science, Harpenden, England, from whom all further information may be obtained, and to the Secretary of the American Section, A. G. McCall, Bureau of Chemistry and Soils, U. S. Department of Agriculture, Washington, D. C.

In order to facilitate matters of transportation to the Congress for the American delegates, a committee was appointed by the American Section of the International Society of Soil Science, consisting of S. A. Waksman, New Jersey Agricultural Experiment Station, and M. J.

Morgan, Connecticut Agricultural Experiment Station. This committee has determined that the approximate cost, for American delegates and those accompanying them, of the Congress and excursion, including tourist transportation from New York and return to New York, will be about $380, with a reduction to members of the International Society of about $20. The committee recommends the following accommodations:

French Liner, Ile de France, leaving New York on July 20 and arriving at Plymouth on July 26, thus allowing three days to be spent in London before the Congress. Return on the *Champlain*, which leaves Southampton on August 24. However, the members have the privilege of returning on other steamers (*Champlain*, Aug. 7[1]; *Normandie*, Aug. 14[2]; *Ile de France*, Aug. 21[2]; *Normandie* Aug. 28[2]; *Lafayette*, Sept. 4[1]; *Ile de France*, Sept. 11[2]), from either Southampton or Havre. The U. S. Revenue Tax of $5.00 must be added to above quotation. It may be noted that railroad transportation from Plymouth to London as well as from London to Southampton will be provided. Members desiring to continue to the Botanical Congress in Amsterdam (September 2 to September 7) may do so without additional transportation expense, railroad tickets being provided from London to Amsterdam, from Amsterdam to Paris, and from Paris to Havre.

The American Shipper of the U. S. Lines leaves New York on July 20 and arrives at Liverpool on July 29. Accommodation tourist class on this steamer will be about $40 less than the above quotation for the round trip. However, no transportation from and to Liverpool will be provided. One may return from London on the *American Merchant* leaving August 30.

Everyone contemplating going to the Congress is urged to write immediately to one of the members of the committee. It is understood that the above quotation will only include the Congress, excursion, and actual transportation and will not include board and lodging and incidental expenses en route to the Congress from Plymouth and after the excursion. It is also understood that the quotation applies only if at least 25 members travel in one group going from New York. The Committee will make arrangements for reservations in line with the above plans.

MEETING OF CORN BELT SECTION OF SOCIETY

THE following program has been arranged for the summer meeting of the Corn Belt Section of the Society to be held at St. Paul, Minn., June 25 to 27:

June 25, Morning, University Farm Auditorium

Joint meeting with Dairy Science Association; American Society of Horticultural Science; Great Plains Section, American Phytopathological Society; American Society of

[1]Slight reduction in above rate.
[2]Slight addition to above rate.

Plant Physiologists; Section O American Association for the Advancement of Science.

Symposium: "Improving the Germ Plasm of Domestic Plants and Animals."

June 25, Afternoon

Field trip to Moscrip's farm, Lake Elmo, to observe studies of pasture management.

June 26, University Farm

Field trip to observe the work of the Divisions of Agronomy & Plant Genetics and Plant Pathology & Botany (in cooperation with American Phytopathological Society and American Society of Plant Physiologists).

June 27, Morning

Field trip to Lake Mille Lacs, visiting on the way the High-lime Peat Experimental Field at Coon Creek and the Low-lime Peat Experimental Field at Page, 12 miles south of lake Mille Lacs.

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SOLUBILITY OF SOIL PHOSPHORUS AS AFFECTED BY MOISTENING AND DRYING BASIC SOILS[1]

T. J. DUNNEWALD[2]

RECENT work with some Wyoming soils indicates that previous treatment of the soil samples affects the results obtained with the modified Denige method for available phosphorus. Some of the older irrigated alfalfa and sugar beet fields develop a difficultly soluble condition of the soil phosphates which affects the crops grown, and, in turn, the livestock which consumes the crops.

Bulk samples of such soils, when air dried and stored for varying lengths of time, exhibited decreases in solubility of the phosphorus in weak acid. Application of superphosphate to such stored soils in greenhouse pots gave large increases of corn. However, watering and cultivation of these soils seemed to increase the solubility of phosphorus to fully as high a point as did fertilizing. Some results of a greenhouse test on such soils, made in 1930, are shown in Table 1.

All the soils shown in Table 1 responded to applications of superphosphate in pot tests. Applications of horse manure, however, gave decreased yields, while watering and cultivation for 10 weeks increased soluble phosphorus about as effectively as did applications of superphosphate. Also on all soils, when watering and cultivation ceased and the soils dried out, the phosphate solubility again decreased. Moisture determinations before and after drying showed that the soils lost from 3 to 8% of moisture, all pots having been kept previously close to 16% moisture.

In the above experiment the samples of soil were removed from the pots by means of a small cork borer tube, dried at 90°C for 1 hour, passed through a 0.5-mm sieve, and weighed out for analysis. The Truog stannous molybdate method was used.[3]

It was believed that the depressed solubility exhibited by the stored soils might be due to heat, light, moisture, carbon dioxide conditions, or to a combination of any of these. Hundred-gram portions of three of the soils were placed in small, clean flower pots and

[1]Contribution from the Agronomy Department, University of Wyoming, Laramie, Wyo. Received for publication January 7, 1935.
[2]Assistant in Soils Investigations.
[3]TRUOG, E. Determination of readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22 : 874. 1930.

treated in various ways before testing for soluble phosphorus. Each pot received treatment once a day and samples of soil were removed after the first, third, and fifth treatments. Table 2 shows the results obtained.

TABLE 1.—*Effect of different treatments on soluble phosphorus in Wyoming soils.*

Treatment	Soluble phosphorus in p.p.m. in soil								
	No. 9	No. 8	No. 7	No. 6	No. 5	No. 4	No. 3	No. 2	No. 1
Sample 2 weeks from field	21	20	9	17	14	48	19	35	11
Group 1, after 10 weeks cultivation and watering in pots	40	44	23	46	40	68	42	75	37
Group 2, superphosphate added, 200 lbs. per acre; cultivated and watered 10 weeks	54	47	16	24	25	54	19	46	25
Pots in group 1 after drying 48 hours	17	8	9	9	10	18	9	23	9
Pots in group 1 after drying 96 hours	16	8	10	10	10	12	9	25	10

TABLE 2.—*Soluble phosphorus in three soils under varied laboratory treatment.*

Treatment	Soluble phosphorus in p.p.m.								
	Soil 1			Soil 2			Soil 3		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Kept at 15% moisture	47	50	40	16	23	14	9	14	14
Heated 30 min. to 95° C.	46	60	43	17	24	13	10	19	17
Stirred dry	49	64	45	17	20	15	9	17	17
Stirred with 15% water	32	52	38	17	21	16	10	15	14
Moistened, stirred, and dried at 95° C.	35	54	47	17	24	12	9	21	14
Stirred and dried at 95° C.	54	59	46	17	29	12	15	24	15
Untreated	54	60	44	17	24	13	14	21	13

A peculiar tendency is shown in these three soils to approach a maximum solubility in the second sampling or the third day of treatment. Drying, stirring, and moistening produced the greatest variations.

Soils not previously stored did not show these variations. Exposure to saturated carbon dioxide air did not cause variations in solubility to any extent, and nitrogen fertilization seemed to produce such variations when accompanied by cultivation and alternate drying

and moistening. When soluble phosphate was added to some of the soils, it quickly became less soluble at first, but under cultivation, drying, and moistening more phosphorus came into solution.

Fairly large bulk samples of the soils were placed in an autoclave for three quarters of an hour at 15 pounds pressure. They were then dried and stored for three months as previously. The steamed soils still showed variations in solubility for the phosphorus after storage, but they did not do so unless they were also stored for a period.

Table 3 shows the reactions of two soils, one of which was steamed and dried but not stored, while the other had a period of storage in addition to the steam treatment.

TABLE 3.—*Effect of different treatments on the soluble phosphorus in steam-treated soils.*

Trial No.	Date	Soluble phosphorus in p.p.m.							
		Check, not steamed air dry, cultivated	Steamed, cultivated, dry only	Steamed, cultivated, 5% moisture	Steamed, cultivated, 10% moisture	Steamed, cultivated, 20% moisture	Steamed, 0.025 gram K_2PO_4, cultivated at 5% moisture	Steamed, 0.025 gram K_2PO_4, kept at 10% moisture	Steamed, cultivated, 0.025 gram K_2PO_4
Virgin Station Soil, Steamed But Not Stored									
1st.......	May 27	11	13	13	14	14	20	21	65
2nd......	May 29	15	15	16	13	14	83	77	84
3rd......	May 30	17	24	19	18	17	84	85	83
Soil Ph...	May 30	8.3	8.3	8.3	8.6	8.6	8.3	8.5	8.3
Wheatland, 16-year-old Alfalfa Soil, Steamed and Stored 3 Months									
1st.......	May 27	12	12	13	15	14	42	25	16
2nd......	May 29	16	14	14	16	15	90	64	91
3rd......	May 30	35	35	25	18	13	125	58	65
Soil pH...	May 30	8.3	8.1	8.1	8.3	8.3	8.3	8.1	8.1

This experiment indicates that the changes in solubility were probably not due to bacterial activity in these soils. Drying, moistening, and cultivation after a period of storage account for the largest variations. Here is suggested an interesting study concerning the possible effects of moistening and drying and of cultivation upon phosphorus solubility in field soils.

Until it became quite obvious that storage caused reduced solubility of phosphorus in these soils, no single soil had been traced clear through the solubility cycle, *viz.*, from field to storage with low solubility and back to high solubility in the greenhouse or laboratory. For this purpose a profile of virgin Experiment Station farm soil and a

profile of a podsolized soil from the timbered mountains at 8,500 feet elevation were collected. The samples were screened, air dried, and tested for soluble phosphorus at once, then put into storage in large earthenware crocks for 30 days and phosphous solubility again tested. Parts of the samples were placed in open paper bags beside the crocks for comparison. Table 4 shows the reductions in solubility of the phosphorus in the acid and basic soils caused by storage for 30 days.

TABLE 4.—*Effects of storage and subsequent moistening upon the solubility of phosphorus in basic and acid soils.*

Soil horizon	pH	Percentage free $CaCO_3$	Replaceable Ca, M.E. per 100 grams dry soil	Soluble P in field soil, p.p.m.	Soluble phosphorus in p.p.m. after		
					Storage in open sacks	Storage in jars 30 days	Finally wetted and air dried
			Experiment Station Soil				
Virgin bench A_0	6.7	1.5	0.642	70	57	36	57
Virgin bench A_1	6.1	0.74	0.557	46	40	31	41
Virgin bench B_0	7.3	2.50	0.725	18	15	18	24
Virgin bench B_1	8.1	11.50	0.485	17	28	20	28
New alfalfa soil A_1	6.8	1.4	—	111	30	32	112
Old garden soil A_1	7.2	1.64	—	120	21	18	116
			Acid Timbered Mountain Soil				
Mull	5.8	0.15	1.538	51	45	44	60
Duff	5.9	0.14	0.568	70	62	60	64
Gray F.S.L A_0	5.9	0.00	0.309	44	38	30	42
Gray F.S.L A_4	5.9	0.00	0.126	13	13	12	14
Gray loam B_1	5.9	0.00	0.105	12	12	11	10
Coarse loam B_2	5.8	0.00	0.133	10	10	10	12
Pink sandy loam C	5.8	0.00	0.308	14	15	13	20

This experiment indicates that the greatest reductions in solubility occurred in the rich garden and alfalfa soils. The acid organic matter and acid soils show much smaller effects than the bench soils. The high lime subsoil horizons act differently than the lower lime surface horizons. The experiment was repeated with an open beaker of water present with the soils in the jar during storage, but no effect upon the result was noted.

SUMMARY

Certain arid and irrigated soils exhibited a reduction in solubility of their phosphorus when stored air dry in a closed dark space. The reduction was as high as 50 to 80% in some soils and was much lower in acid than in basic soils.

The solubility was restored almost completely by moistening the stored soil with distilled water and allowing to dry overnight.

The horizons containing the organic matter were most affected and the high lime subsoils reacted differently. The phosphorus made soluble by cultivation and moistening of stored soils seemed to be available for plant growth in pots in the greenhouse.

Hydroxyl ions are active in phosphorus replacement and the results cited in this paper may possibly be explained on this basis.[4]

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[4]McGeorge, W. T., and Breazeale, J. F. Studies on iron, aluminum, and organic phosphates and phosphate fixation in calcareous soils. Ariz. Agr. Exp. Sta. Tech. Bul. 40. 1932.

Breazeale, J. F., and McGeorge, W. T. Nutritional disorders in alkaline soils as caused by deficiency of carbon dioxide. Ariz. Agr. Exp. Sta. Tech. Bul. 41. 1932.

Ravikovitch, S. Adsorption of the phosphoric acid ions by soils. Soil Science, 38 : 219. 1934.

PHOSPHATE AVAILABILITY IN CALCAREOUS SOILS: A FUNCTION OF CARBON DIOXIDE AND pH[1]

W. T. McGeorge, T. F. Buehrer, and J.F. Breazeale[2]

THE rapidly expanding use of phosphate fertilizers in the Southwest, and in many parts of the West in general, is rather convincing evidence of the state of phosphate availability which exists in these soils. Briefly stated, the soil conditions are as follows: (a) The presence of carbonato-apatite as the dominant natural phosphate; (b) an excess of solid-phase calcium carbonate, and (c) varying amounts of free hydroxyl ions. There is no deficiency of potential phosphate reserve, as the presence of similar amounts of carbonato-apatite in non-calcareous soils would be sufficiently available to supply the phosphate needs of crops for many years. The phosphate problem of the Southwest, therefore, largely concerns an environment which depresses the ionization or breaking down of the carbonato-apatite complex. In this environment the presence or absence of carbon dioxide is a dominant factor.

The literature concerning carbon dioxide or carbonic acid in soils is very extensive and clearly portrays its importance in soil processes. This, however, is most fully appreciated by the students of alkaline-calcareous soils. There is scarcely a single undesirable soil property of alkaline soils which does not respond favorably to carbon dioxide. This applies not only to the various changes needed for alkali soil reclamation, but also to plant food availability and its absorption by plant roots. The continued observance of the importance of carbon dioxide to the fertility of southwestern soils has led us to suggest that it is the greatest growth-limiting factor in the cropping of these soil types.

The rôle of carbon dioxide in phosphate availability and its absorption by roots is an outstanding property. It functions in reducing the pH of the soil, or OH ion concentration of the soil solution, which in turn favorably influences phosphate nutrition in three ways, as follows:

1. Ion absorption by plant roots is greatly restricted by the presence of OH ions in the soil solution. Carbon dioxide neutralizes soluble hydroxides and carbonates.
2. The ratio of $\frac{H_2PO_4^-}{HPO_4^{--}}$ is reduced by the presence of OH ions and since plants show a preference for the $H_2PO_4^-$ ion the rôle of carbon dioxide in increasing this ratio is self-evident.
3. The solubility of carbonato-apatite is reduced by the presence of solid-phase calcium carbonate. Carbon dioxide attacks the solid-phase calcium carbonate as well as the calcium carbonate of the

[1]Contribution from the Department of Agricultural Chemistry and Soils, Arizona Agricultural Experiment Station, Tucson, Ariz. Also presented at the annual meeting of the Society held in Washington, D. C., November 23, 1934. Received for publication January 28, 1935.

[2]Head of Department, Physical Chemist, and Research Biochemist, respectively.

carbonato-apatite and thereby increases the solubility of phosphate in the soil solution.

Thus, the solution of the phosphate problem is one of using soluble phosphate fertilizers and getting larger amounts of carbon dioxide into the soil environs.

Phosphate rock or bone are of little or no value in alkaline calcareous soils. On the other hand, response to soluble phosphates has been demonstrated numerous times and the response is immediate if a deficiency exists. This is illustrated by the following experiment. At the University Farm, Tucson, Ariz., an increase of 60% in yield of alfalfa hay was obtained in less than 4 weeks by applying 100 to 200 pounds per acre of ammonium phosphate between cuttings.

In recognizing the favorable influence of carbon dioxide in phosphate nutrition in alkaline calcareous soils, it is self-evident that the efficiency of both phosphate fertilizer and the natural soil phosphate will be greatly enhanced by the presence of free carbon dioxide in the soil environs.

EXPERIMENTAL

Three methods are under study for supplying carbon dioxide to our soils, namely, aeration, organic manures, and chemicals. While aeration is a step in the right direction, largely due to the stimulating effect on root respiration and thereby greater exudation of carbonic acid, it does not of itself exercise a sufficiently effective influence upon the pH of the soil nor the solid-phase calcium carbonate. Organic manures have given excellent response which is in agreement with the results obtained by Pittman (4)[3] in Utah, and they are especially valuable when applied along with phosphate fertilizers. On the other hand, large quantities of organics are not always available in arid regions and this suggests the use of acids in the irrigation water. With unlimited supplies of calcium carbonate in our soils and with a cheap source of acid, this appears to be a feasible way of reducing the pH of the soil solution and at the same time generate a supply of carbon dioxide.

A limited number of experiments have shown this premise to be correct. For example, in a series of experiments in which corn plants were irrigated with water brought to pH 3.0 by sulfuric acid as compared with water of pH 7.0 and 8.5, which cover the pH range of our irrigation waters, the plants in the pots irrigated with the acidified water absorbed considerably more phosphate (2). Since the water at pH 3.0 contains only about 50 p.p.m. sulfuric acid and since this is neutralized immediately on contact with the soil, the effect of the acid is in reality one of carbonic acid. The manner in which the carbonic acid operates is clearly illustrated by the following experiment and discussion of the equilibria involved.

Three pots of acid-washed silica sand were prepared as follows:

No. 1. Control, sand only.

No. 2. Sand plus 5% calcium carbonate and 0.5 gram phosphate rock.

No. 3. Prepared exactly as No. 2.

[3]Figures in parenthesis refer to "Literature Cited," p. 335.

All pots were planted to tomatoes and the first two were irrigated with tap water, while the third pot was irrigated with water saturated with carbon dioxide. The tap water contained 10 p.p.m. nitrate and a trace of phosphate. The comparative growth of the plants at the time of harvest is shown in Fig. 1. The plants were dried and the dry

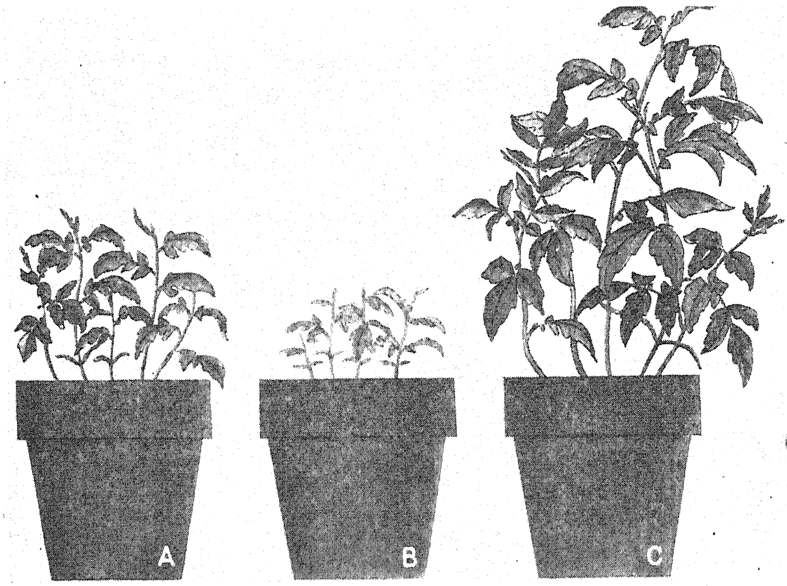

FIG. 1.—(A) Control, silica sand only; (B) phosphate rock and $CaCO_3$ added to sand; (C) same as B. Pots A and B watered with tap water; pot C with water saturated with CO_2.

weight and percentages of nitrogen and phosphate determined. The solubility of the phosphate in the pots was also determined by analyzing the leachate from the pots. These data are given in Table 1.

TABLE 1.—*Dry weight of plants and percentage of N and PO_4 in plants and PO_4 in leachate from pots.*

Pot No.	N, %	PO_4, %	Dry weight of plants, grams	PO_4 in leachate, p.p.m.
1	0.050	0.00302	1.175	0.5
2	0.006	0.00302	0.200	0.0
3	0.315	0.01750	2.625	1.75

These data are self-explanatory and clearly show the value of carbon dioxide in offsetting the undesirable effects of solid-phase calcium carbonate, thereby improving the availability of phosphate of carbonato-apatite. In our alkaline calcareous soils, where aeration is poor, carbon dioxide absent, and little or no soluble calcium salts

are present to furnish the common ion calcium, pH values of 9.0 or even higher may develop from the hydrolysis of calcium carbonate. Thus, carbon dioxide serves the double purpose of reducing the pH to the range where phosphate ion absorption by roots is most active and of breaking down the carbonato-apatite compound. The use of carbon dioxide under field conditions, such as by applying "dry ice" to the irrigation water, is questionable; but with Arizona soils containing 2 to 10% calcium carbonate, it may be economically generated by the use of acids or sulfur. Under field conditions these acid soil amendments have produced increased phosphate absorption by crops on the soils in question.

It should be understood that the soils under discussion are semi-arid soils and practically devoid of organic matter. The above principles would not apply to calcareous soils containing appreciable amounts of organic matter for such soils would possess a microbiological source of carbon dioxide and could not attain the high pH value of alkaline calcareous soils in semi-arid districts.

THEORETICAL

On account of the three-stage ionization of phosphoric acid, all of the various intermediate phosphate ions will be present in solution, their proportions depending upon the pH. By calculation from the three ionization constants it was found that at pH 6.8, which approaches optimum for most plants, HPO_4^{--} and $H_2PO_4^-$ are present in equimolecular proportions (1). The free energy change for the conversion of HPO_4 into $H_2PO_4^-$ is such that these forms are easily converted into one another, being limited only by the solubility of the phosphate salt and the pH of the solution. It is self-evident that pH is an important limiting factor in the absorption of phosphate since plants show a definite preference for the $H_2PO_4^-$ ion.

As will be shown later, in order for natural phosphates to become soluble in alkaline calcareous soils, they must first pass through the dicalcium phosphate form. In view of this, equilibrium measurements must include both the carbonato-apatite and dicalcium phosphate and involve the action of both carbon dioxide and neutral salts which are usually abundant in such soil types.

The effect of neutral salts upon the solubility of these phosphates has been found up to a limiting concentration of about 0.05 N to increase the solubility of dicalcium phosphate, even when common ions are present. Beyond this limit, the common ion effect becomes pronounced. In all cases, however, the effect of pH is far greater in reducing the solubility than is the effect of neutral salts in increasing it. In the presence of both OH^- and CO_3^{--}, the conversion of dicalcium phosphate into carbonato-apatite was found to proceed readily, though not very rapidly.

Since it has been definitely established (3) that the insoluble phosphate which predominates in alkaline calcareous soils is carbonato-apatite, a series of equilibrium experiments were conducted to determine the behavior of these compounds. Dicalcium phosphate and carbonato-apatite were prepared pure and equilibrated, at various pH values, and in the presence of different salts, and the equilibrium

solutions analyzed. Similar experiments were also made with solutions containing different amounts of carbon dioxide. These experiments showed that the conversion of relatively insoluble dicalcium phosphate into the less soluble carbonato-apatite in each case proceded to an equilibrium depending on the pH.

When the equilibrium constants for the action of carbonic acid on these two phosphate compounds were calculated the following results were obtained: (A) $CaHPO_4 + H_2CO_3 = Ca^{++} + HCO_3^- + H_2PO_4^-$, the equilibrium constant for which is 3.07 x 10^{-5}; and (B) $(Ca_3(PO_4)_2)_3.CaCO_3 + H_2CO_3 = 10Ca^{++} + 14\ HCO_3^- + 6H_2PO_4^-$, the equilibrium constant for which is 5.7 x 10^{-40}.

The extremely small value of this latter constant suggested that the reaction as written must be very improbable, though we know that carbon dioxide will make carbonato-apatite go into solution to a limited extent. If the constant for the second reaction is recalculated, using the data obtained for it by experiment but with the mathematical expression for the equilibrium constant the same as that for the first reaction, we obtain the value 2.52 x 10^{-5}. This value checks that of reaction A very closely and leads to the conclusion that dicalcium phosphate controls the equilibrium in alkaline calcareous soils in the manner shown by the following equation: (C) $(Ca_3(PO_4)_2)_3.CaCO_3 + 7H_2CO_3 = 6CaHPO_4 + 4Ca^{++} + 8HCO_3^-$.

From equation C it also follows that if phosphate is to become available, the hydrogen-ion concentration must be sufficient to overcome the common ion effect of Ca^{++} ions and the alkalinity arising from the $CaHPO_4$ and HCO_3^- ions. An exceptionally large concentration of carbonic acid must be present to effect such solubility under alkaline calcareous conditions and even then its solvent action will be limited by the gradually increasing concentration of bicarbonate ions.

It is thus shown that both experimental and theoretical proof can be offered to emphasize the important part which carbon dioxide plays in the availability of phosphate in alkaline calcareous soils. This applies not only to the availability of the natural phosphate but also to the availability and absorption of that added as fertilizer.

SUMMARY

Briefly summarizing, the problems of phosphate availability and phosphate fertilization in alkaline calcareous soils are largely dominated, if not completely governed, by three factors. First, solid-phase calcium carbonate, which is present in abundance, reduces the solubility of the phosphate in carbonato-apatite because of the combined common ion effect of Ca^{++} and CO^{--}. Second, free hydroxyl ions reduce the absorption of phosphate ions by plant roots. Third, free hydroxyl ions modify the normal step ionization of orthophosphate in such a manner that the H_2PO_4 ion, which is preferred if not demanded by plant roots, is largely absent from the system.

Carbonic acid and pH are the key to the availability of phosphate in these soils and our knowledge of the natural form of phosphate present in these soils, together with its properties, suggests that

only water-soluble phosphates be used as fertilizer, and this has been demonstrated experimentally.

LITERATURE CITED

1. BUEHRER, T. F. The physico-chemical relationships of soil phosphates. Ariz. Agr. Exp. Sta. Tech. Bul. 42. 1932.
2. MCGEORGE, W. T. The relation of potential alkalinity to the availability of phosphate in calcareous soils. Soil Science, 38 : 1934.
3. ————, and BREAZEALE, J. F. The relation of phosphate availability, soil permeability and carbon dioxide to the fertility of calcareous soils. Ariz. Agr. Exp. Sta. Tech. Bul. 36. 1931.
4. PITTMAN, D. W. Effect of manure and phosphorus fertilizer on the yield and composition of alfalfa hay. Utah Agr. Exp. Sta. Bul. 247. 1934.

THE INFILTRATION CAPACITY OF SOILS IN RELATION TO THE CONTROL OF SURFACE RUNOFF AND EROSION[1]

G. W. MUSGRAVE[2]

DESPITE the fact that differences in soil types are generally recognized, the pronounced effect of the infiltration capacity of the soil upon the type of erosion control measures which should be recommended has been largely overlooked.[3] Control measures have been recommended that are practically uniform for entire states, whereas the soils within such areas may require entirely different treatment. The absence of quantitative data upon the infiltration capacities of different soils has undoubtedly been the principal reason for the general omission of this factor in the practical application of control measures in the field.

For erosion problems, and in connection also with studies relating, for example, to soil moisture, a method for determining the infiltration capacity of the soil in the field may be most helpful. It has been shown (8)[4] that one of the primary groups of factors affecting the amount of surface runoff from soil in the field is its infiltration capacity. The general pronounced effect of this factor is appreciated only when quantitative data are available. If two soils differ in capacity by as much as ½ inch infiltration per hour over a 4-hour period, the amount of protection provided would differ by 2 surface inches. In many instances this is an amount greater than the effect of the treatment itself.

Any method for the measurement of the infiltration capacity of a soil to be of value in the design of measures for the control of surface runoff obviously must be applicable to the field structure of the soil. Not only that, but it should be applicable to such structure of the soil as permits its *lowest* normal capacity. The results of such measurement giving the *minimum* capacity of the soil may then be safely used in combination with the known capacities of such treatment or treatments for impounding water upon the surface as it may be desired to use.

The purpose of this study has been to develop a method for determining the infiltration capacity of the soil in the field, and to apply the results of such study to the design of treatments for the control of surface runoff and erosion.

[1]Contribution from Soil Erosion Investigations, U. S. Dept. of Agriculture. Also presented before the annual meeting of the American Soil Survey Association held in Washington, D. C., November 22, 1934. Received for publication February 13, 1935.

[2]Scientist in Soil Erosion and Superintendent, Soil Erosion Stations, Clarinda, Iowa, and Bethany, Mo.

[3]As defined by the section on Hydrology, Amer. Geophys. Union (Trans. Amer. Geophys. Union, Part II, 1934, page 295), infiltration is "The process by which liquid water enters the zone of aeration. It includes the formation and upbuilding of films around soil-grains through wetting by rainfall, melting snow, or temporary sheet-water, and the subsequent progressive downward movement of mobile water through the soil by film-flow after the demand for pellicular water has been satisfied."

[4]Figures in parenthesis refer to "Literature Cited," p. 345.

LITERATURE

Middleton (6), in his study of the properties of soils which influence erosion, has compared the maximum water-holding capacity of seven erosive soils with that of four non-erosive soils. The average for the erosive soils is 42.9% and for the non-erosive 56.2%. Also, he has shown the pore space for these soils. The erosive ones average 32.5% and the non-erosive 45.1%. These comparisons would undoubtedly indicate a higher infiltration capacity for the non-erosive than for the erosive soils. In his study, no comparisons were made between runoff and percolation rates, presumably because of the absence of runoff data. It is probable that a very much greater correlation would be found between runoff and percolation rates than between erosion and percolation rates.

Slater and Byers (9) made a laboratory study of the percolation rates of soil cores which were obtained in the field and forwarded to the laboratory without structural change. The Iredell silt loam, recognized as a highly erosive soil (6), showed a percolation rate of 0.030 inch per hour through open end cores of 14 cm length, while the Davidson clay, recognized as a relatively non-erosive soil, gave a percolation rate of 1.020 inches per hour through open end cores of 20 cm length.

Buehrer (2) has described a method of indicating the structure of a soil based upon the volume-of-flow rate of air through the soil column. He derives an equation for the mechanism of such flow and shows that it is a constant over a wide range of physical conditions. He shows that a comparison between the structure constant and the porosity of various soils is not simply linear as might be expected if all pores were continuous.

Auten (1) has compared the rates of water absorption in old growth forest soils and in adjacent field soils. The forest soils were found to be more porous and h a higher absorption rate than the field soils.

A review of the literature is given by Slater and Byers (9), who note that "very little information is extant concerning the percolation of water through soils of undisturbed structure." It may be added that the above statement is particularly true as applied to the entire soil profile. It is obvious, for example, that percolation rates for a permeable A horizon if lying above an impermeable B horizon may be quite different when determined for the single horizon than when determined for the profile. Ordinarily air must be forced in advance of the moving water. Such movement is very slow through soils of "heavy" structure.

METHODS

Three methods have been used for the determination of the field rate of infiltration of two soil types, namely, the Marshall silt loam, a permeable soil, and the Shelby silt loam, a comparatively impermeable soil. The physical and chemical properties of these soils have been described by Middleton, Slater, and Byers (7).

These methods of measurement were as follows: First, Horton's (3) method in which the available runoff records from known areas were compared with rain intensity curves. The measured runoff was then deducted from the portion of the intensity curve covering the runoff period. The remainder, indicated as the amount of infiltration, was then converted into inches per hour. The second method employed the data from the erosion type lysimeters. In this installation runoff and percolate were measured from soils of normal field structure and of definite surface slope, the columns of soil being 3 feet in length and 3 feet in diameter. The third method was devised in order to provide more rapid progress in obtaining the needed information than was possible with the other methods.

Under normal rainfall the infiltration capacity of the Marshall silt loam is infrequently reached and then only for comparatively short periods. The method used (which provides data even in drouth years) employed the application of water in measured quantities and under uniform head to field soils *in situ*.

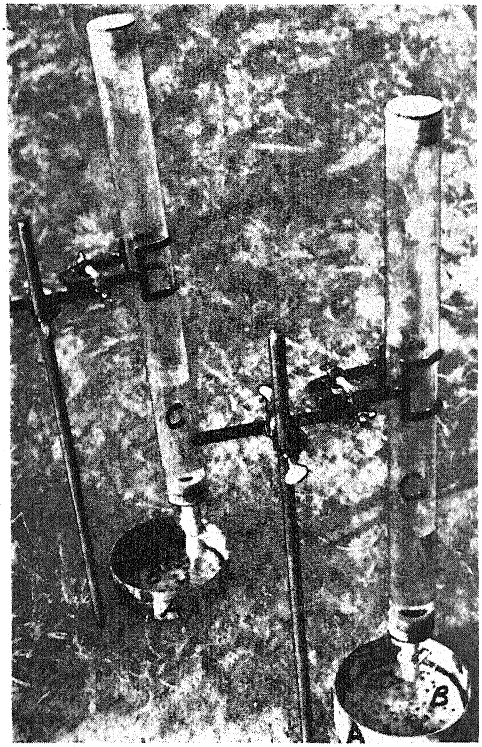

FIG. 1.—Apparatus used in making infiltration measurements.

A, seamless tube, 6 inch diameter and of sufficient length to penetrate into the B horizon; B, perforated disk lying on top of soil column; C, calibrated tube for applying water to soil under constant head.

The equipment is shown in Fig. 1. Cylinders usually 6 inches in diameter and of sufficient length to reach the B horizon are forced into the soil by means of jack screws actuating against a convenient movable weight (tractor or loaded truck). These cylinders are of seamless steel tubing sharpened on the lower outside extremity by grinding to a 17° angle. For the Marshall series lengths of 8, 14, and 18 inches have been used, depending upon the depth of the A horizon and its structural condition. For the greater depths of soil and for conditions of very open structure the measurements have been made with 12 or more tubes of 18-inch length. A 1,000-cc dispensing burette with enlarged lower opening and attached rubber tubing and pinch-cock is placed in position above the soil core. A perforated disk is placed on the top of the soil to prevent the development of turbidity when the application of water is made, inasmuch as under such conditions the rate of flow has been shown to be greatly reduced (5).

Ordinarily, from 6 to 12 units are installed for the purpose of making a single determination (Fig. 2). The burettes are filled with water to the upper mark and tightly stoppered. They are then installed so that the lower extremity is approximately 4 to 5 mm above the perforated disk. Thus, a head of water of that height (which appears to be the minimum feasible in practice) is established. During the first half hour readings are made at 5-minute intervals. During the next succeeding hour readings are made at 15-minute intervals. Subsequently, readings are made at 1-hour intervals or greater, depending upon the type of soil and the rate of flow.

RESULTS

Horton's method has been applied to both of the soils in an analysis of runoff covering a 2-year period on the Marshall series and a 3-year period on the Shelby series. Data from the erosion type lysimeters covering a 24-month period for the Marshall series are available. Without going into detail with reference to these results, it may be said that they are in substantial agreement with the results shown for the special method of measurement described herein.

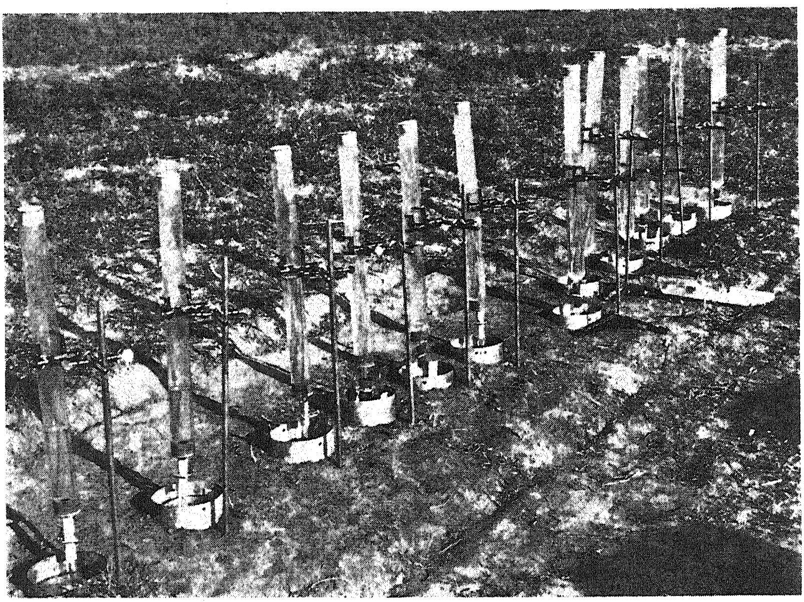

FIG. 2.—Making infiltration measurements in the field.

A battery of 12 units in operation upon Marshall silt loam, sod removed just prior to making measurements; soil moist.

In Fig. 3 the results for a period of 6 hours for the Marshall and Shelby series are shown graphically. These determinations were made in the case of the Shelby series upon a profile located approximately 25 feet distant from the control plats of the Soil Erosion Experiment Station at Bethany, Mo. The determinations were made Sept. 18 after a 1.76 inches rainfall on Sept. 13, a rainfall of 0.37 inch on Sept. 14 to 15, and a 0.16 inch rainfall on Sept. 17. The area was in blue-grass sod and the tubes were inserted after the surface vegetation had been pared off. The profile upon which these determinations were made contains a deeper A horizon than does the profile of the control plats upon which serious erosion has occurred. No less than 4 inches of deep black soil was present in the profile studied. The rates for this impermeable soil are, therefore, believed to be conservatively comparable with those of the permeable Marshall. The site upon

which the Marshall determinations were made lies approximately 100 feet distant from the control plats of the Soil Erosion Station in Page County, Iowa. This profile is practically identical with the profile within the plats themselves. In both instances the locations are upon the same contour as the control plats and have practically identical substructure as that within the plats. On the Marshall site the sod was likewise removed prior to forcing the tubes into the soil.

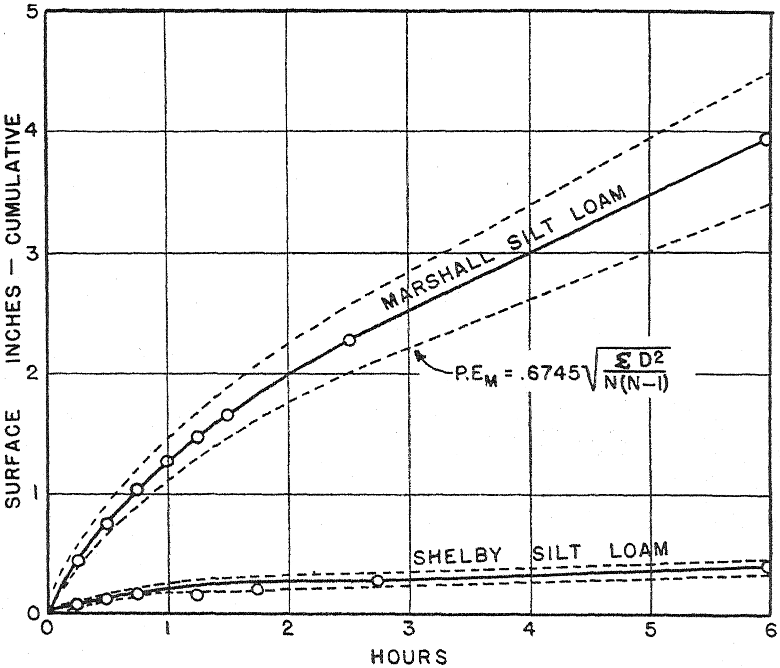

FIG. 3.—Cumulative infiltration for two soils of field structure, both moist and with previous sod surface pared off smoothly.

It is seen from the plotted probable error that the uncontrolled variation is rather large. This seems to be true of most of the reported results for percolation rates. Apparently the soil in its various slight changes in structure is most sensitive to the passage of either air or water. Only by means of ample replication and by most careful procedure is it possible to obtain reliable results. Despite the rather high probable error shown in Fig. 3, it is seen that the difference between the infiltration rates for the two soils is significant.

Plotted curves show that in the first 15 minutes the infiltration rate upon the Marshall silt loam exceeded that upon the Shelby silt loam by 0.38 inch. In the first half hour the Marshall exceeded the Shelby by 0.64 inch. In the first 45 minutes the excess was 0.88 inch. Within a period of 6½ hours the differences exceeded 3.76 inches.

It is of interest to check the above data with the actual measured runoff for Shelby silt loam and Marshall silt loam as determined on

two of the control plats of the Soil Erosion Experiment Station near Bethany, Mo., and two of the control plats of the Soil Erosion Experiment Station near Clarinda, Ia. At both stations there are control plats of like length and cropped continuously to corn. The comparative runoff from these four plats as a percentage of the total rainfall is given in Table 1.

TABLE 1.—*Measured runoff on Shelby and Marshall silt loam in 1933 as percentage of total yearly rainfall, data from control plats of erosion stations.*

Crop	Slope, feet	Shelby	Marshall	Ratio of Shelby: Marshall
Continuous corn......	145.2	27.69	4.10	6.8:1
Continuous corn......	72.6	31.00	4.32	7.2:1

The ratio of runoff of Shelby to Marshall shows that from 6.8 to 7.2 times as much of the respective rainfall ran off from the Shelby as from the Marshall soil.

These ratios of runoff may be compared (Table 2) with the ratios of the infiltration amounts for the same soils as determined by the method of direct measurement described above, and as shown on the graphs of Fig. 3.

TABLE 2.—*Ratios of infiltration amounts for Marshall silt loam to Shelby silt loam for stated periods of time as determined by direct measurement.*

	½ hr.	1 hr.	1½ hrs.	2½ hrs.	6½ hrs.
Ratios.............	6.3:1	7.8:1	8.2:1	8.2:1	9.2:1

It is seen from Table 2 that for a half hour period the Marshall silt loam took in 6.3 times as much water as the Shelby. For a 1-hour period the Marshall exceeded the Shelby by 7.8 times. Inasmuch as the majority of rains causing runoff were of comparatively short duration, it is apparent that a ratio of about 7:1 for the shorter periods of time most probably represents the conditions quite accurately. However, the frequency, intensity, and duration of rains to which the two soils were subjected were of course not the same. Thus, under the conditions there is unusually good agreement in the comparison of the two soils by these two diverse criteria, as well as between the three methods which were used for determining the infiltration capacity.

The supreme importance of this factor in the control of surface runoff is at once apparent. Assume that any particular treatment impounds upon the surface of a field 1½ surface inches of water. Taking this amount as a basis of calculation, the protection which is afforded by such a treatment upon the Shelby silt loam is shown in Fig. 4. In this figure the infiltration rate is plotted above the 1½ surface inches which it may be assumed was impounded by a given treatment. Thus, the total degree of protection afforded by the infiltration and the impounding of surface water is somewhat less than 2 surface inches in a 6-hour period.

A highly intensive rain has been plotted upon the same graph for purposes of comparison. The maximum observed rainfall reported over a 42-year period at Des Moines, Iowa, totalled 0.66 inch for a 5-minute period, 1.36 inches for a 15-minute period, and 2.65 inches for a 60-minute period. This curve has been extended arbitrarily to a maximum of 4½ inches in 5½ hours. It is thus seen that the

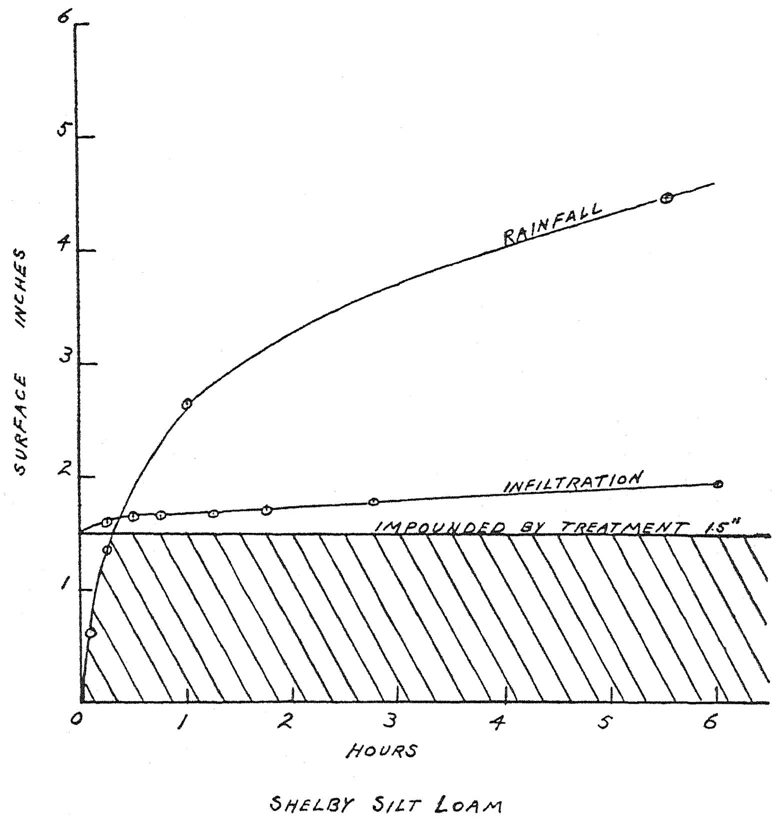

FIG. 4.—Protection provided against runoff on Shelby silt loam for rain of rare intensity and duration and for treatment which impounds 1.5 surface inches of water.

treatment on the Shelby series provides complete protection upon soil of similar structure and moisture conditions to that upon which the infiltration data have been obtained for something less than 24 minutes for a rain of this intensity and duration. At the end of 1 hour nearly 1 inch of rain will have fallen which can neither be impounded upon the soil nor retained within the soil itself. At the end of a 5-hour period there would be an excess of rainfall over protection amounting to 2.45 surface inches under such conditions. This amount would necessarily be lost as surface runoff.

Similar data for the Marshall silt loam are shown graphically in Fig. 5. For a treatment impounding a like amount of water and for a rainfall of like intensity and duration, complete protection is provided throughout the entire period. As a matter of fact the curves would indicate that at the end of a 5½-hour period there would remain a margin of safety approximating a surface inch under these conditions.

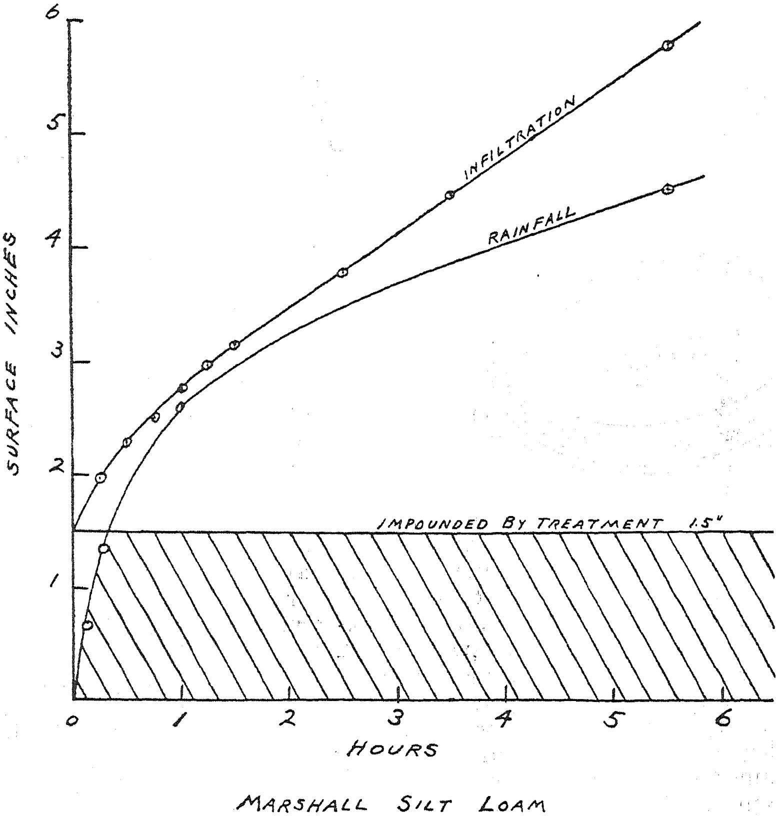

FIG. 5.—Protection provided against runoff on Marshall silt loam for like rain and treatment to that shown in Fig. 4.

DISCUSSION

There are a great many factors which affect the infiltration rates. A separate study is being made of these and will be reported later. However, for the purpose of determining erosion control treatments our interest lies primarily in minimum rates. The results reported herein are for uncultivated moist soil without vegetative cover and are believed to approximate closely the minimum field rates for each soil.

The amount of water which is impounded by such treatments as terracing, contouring, etc., is approximately determinable. An in-

strument survey giving surficial elevations and plotted on an enlarged scale supplies the essential needs for such conditions as contoured rows and closed end level terraces.

The infiltration capacity of field soils may be determined in several different ways as indicated above. The methods which depend upon normal rainfall are not as suitable for the reason that the application of rain at maximum rates occurs but infrequently. Hence the necessity for a method which will permit the artificial application of water as described herein.

The total of the water impounded, together with the water passing into the soil, permits a fairly precise determination of the volume of precipitation which the treatment will retain upon the field. This total when compared with rainfall curves for the area provides definite information as to the intensities and durations of rain which will cause surface runoff, as well as the amount of such runoff.

Where rainfall data are complete enough to provide frequency curves, a record may be selected which will fit the degree of protection desired. Thus, the rainfall curve of Figs. 4 and 5, with an expectancy of once in 40 years, may be more intensive and of a larger size than economic practice would dictate. Probably a lesser amount, which for example would be exceeded once in 30 years, could be selected as the standard for determining the capacity of the treatment. Even a smaller amount which would be exceeded but once in 20 years might be selected as suitable in the interest of economy. However, in any case, the frequency and probable amount of runoff would be known.

Less precision in the pre-calculation of subsequent erosion is perhaps possible at the present time than is the case for surface runoff. The density of runoff is affected by certain properties of the soil which are probably well indicated by the erosion ratio. In addition, however, the type of vegetation, the length of slope, and many other factors come into play. Data on these points are now being obtained at the various erosion experiment stations.

Under conditions where such factors as amount of water impounded, the infiltration capacity, and the effect of the treatment upon density of runoff are reasonably well determined it seems probable that the degree of protection provided in the field may likewise be predetermined with a fair degree of exactitude. Conversely, where the infiltration rate is known and the effect of the treatment upon density of runoff is likewise known, it seems not impossible that the design of the control treatment for impounding surface water may be determined within reasonable limits of accuracy.

CONCLUSIONS

It is obviously erroneous to attempt to apply like measures for the control of surface runoff and erosion to both permeable and impermeable soils.

The amount of erosion occurring from a field for a rain of given intensity and duration may be approximately predetermined for a given set of conditions if quantitative data are available for (a) amount of water impounded upon the surface of the field by the treatment; (b) the rate of infiltration for the soil and conditions; and

(c) the density of the runoff (pounds of soil per cubic foot of runoff) for the soil and the treatment.

The amount of water impounded by such treatments as terracing, contouring, etc., is approximately determinable. Methods are shown and specific cases given for the measurement of the infiltration capacity of field soils. A considerable body of data already exists which gives the effects of various treatments of many soil types upon the density of runoff.

Before erosion control measures are designed and recommended for general application in the field, their probable effect should first be calculated and the degree of protection which they afford compared with the rainfall records of the area.

LITERATURE CITED

1. AUTEN, JOHN T. Porosity and water absorption of forest soils. Jour. Agr. Res., 46 : 997–1014. 1933.
2. BUEHRER, T. F. The movement of gases through the soil as a criterion of soil structure. Ariz. Agr. Exp. Sta. Tech. Bul. 39. 1932.
3. HORTON, ROBERT E. The rôle of infiltration in the hydrologic cycle. Trans. Amer. Geophys. Union, 14th Ann. Meet. 1933.
4. JARVIS, C. S. Rainfall characteristics. Trans. Amer. Soc. C. E., 95 : 410. 1931.
5. LOWDERMILK, W. C. Influence of forest litter on run-off, percolation, and erosion. Jour. For., 28 : ——. 1930.
6. MIDDLETON, H. E. Properties of soils which influence soil erosion. U. S. D. A. Tech. Bul. 178. 1930.
7. ————, SLATER, C. S., and BYERS, H. G. Physical and chemical characteristics of the soils from the erosion experiment stations. U. S. D. A. Tech. Bul. 316. 1932.
8. MUSGRAVE, G. W. A quantitative study of certain factors affecting soil- and water-losses as the logical basis for developing practical methods of erosion control. Trans. Amer. Geophys. Union, 15th Ann. Meet. 1934.
9. SLATER, C. S., and BYERS, H. G. A laboratory study of the field percolation rates of soils. U. S. D. A. Tech. Bul. 232. 1931.

THE APPLICATION OF A MODIFIED PROCEDURE IN NITROGEN TRANSFORMATION STUDIES IN FOREST SOILS[1]

HERBERT A. LUNT[2]

IN nitrification studies with forest soils we had been following the conventional practice of treating the horizon as a unit, i.e., sampling and incubating each horizon separately under optimum conditions of temperature and moisture. Preparation of the samples included mixing and sometimes sieving the mineral soil and cutting the duff material into short lengths (⅛ to ¼ inch) in a food chopper.

While such procedure has its value and should not be discarded, it appears to be rather inappropriate for forest soils in which there may be from two to four distinct horizons in the upper 6 to 8 inches of soil. In the natural state these horizons are in intimate contact with each other and it is a questionable procedure to incubate them separately. Furthermore, there is some doubt as to the advisability of holding the incubating samples at optimum conditions of moisture and temperature when the natural environment may be far from optimum. Therefore, we have tried sampling the whole upper 7 inches as a unit, and incubating the samples out of doors where they are subject to the natural fluctuations in temperature. No separation of the horizons is made until the time of analysis.

DETAILED PROCEDURE

A steel sampling tube, 3 inches in diameter inside and 7 inches long, was constructed out of 3-inch pipe and equipped with an inside collar at the cutting end and a heavy outside collar at the opposite end (Fig. 1). The tube was pushed into the soil to its full length. Usually the upper portion of the forest soil profile is sufficiently loose so that nothing more than standing or treading on the cylinder is necessary to get it into the ground. Generally it is advisable to cut through the duff first with a hunting knife.

The cylinder full of soil and duff was then dug out with a spade and the soil pushed out the top end by means of a plunger into a quart cardboard ice cream container of the same size and open at both ends. The sample was then transferred to a glass jar of the same size and shape. The purpose of the cardboard carton was to enable the operator to have the sample right side up in the glass jar.

Closed with a glass top, the sample was then taken to the laboratory, weighed, and placed out of doors on a shaded bench and allowed to remain there 3 months. By permitting the top to rest loosely on the jar, movement of air was ample and no other means of ventilation was provided. Water was added about every 2 weeks, if necessary, to bring the samples up to weight. Usually from three to five samples were collected in each locality with one or more extra for immediate testing. The time of the original sampling coincided fairly closely with the initiation of biological activity in the spring, usually about May 1 in this climate.

At the end of the incubation period the sample was slipped out into a pan, slit

[1]Contribution from the Department of Soils, Connecticut Agricultural Experiment Station, New Haven, Conn. Also presented at the annual meeting of the Society held in Washington, D. C., November 23, 1934. Received for publication February 11, 1935.

[2]Associate in Forest Soils Research.

open lengthwise, and several portions tested for reaction and for ammonia and nitrate nitrogen by the spot plate method (4).[3] In addition, spot plate tests may be made for soluble calcium, magnesium, phosphorus, potassium, manganese, aluminum, and iron. Finally, as a check on the spot plate tests, a composite of all of the samples from one locality was analyzed quantitatively for ammonia and nitrate nitrogen.

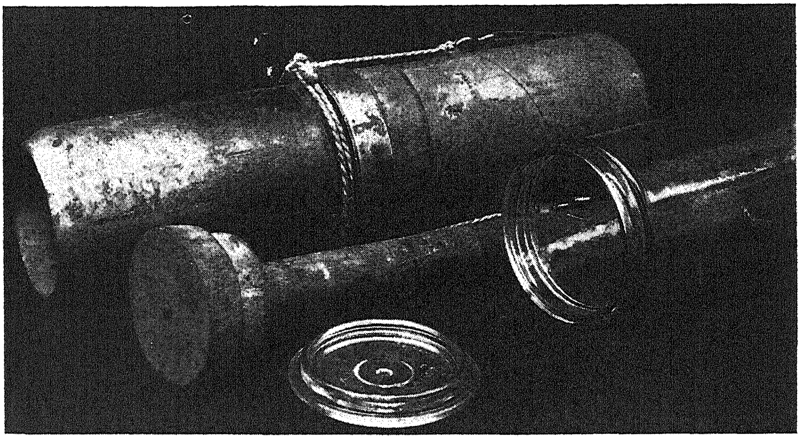

FIG. 1.—Steel sampling tube with cardboard carton attached for receiving the soil sample, plunger used in transferring sample from one container to another, and glass jar used for storage during incubation.

EFFECT OF CONTAINER ON NITRIFICATION

It was originally planned to use cardboard ice cream containers, but it was found that the container interfered with the accumulation of soluble nitrogen to a very serious degree. Jefferies[4] has encountered the same difficulty. Presumably, both the cardboard and its wax coating are responsible, for similar results were obtained when the container was covered with two heavy coats of paraffine regardless of whether the container was made of cardboard or glass. A coating of asphaltum paint was much less harmful than wax, but it did not permit as complete a nitrification as did glass alone. Some of the findings pertinent to this question are shown in Tables 1 and 2.

TABLE 1.—*Effect of container upon nitrification, 3 months' incubation.*

	Treatment applied quart size cardboard ice cream containers				Glass jars
	1 coat wax outside	1 coat wax inside and outside	2 coats wax inside and outside	Asphaltum paint inside and outside	
NO_3 nitrogen, p.p.m.	2.2	21.2	69.2	63.9	77.1
Water added to maintain constant weight, cc.	149	316	5	72	12

[3]Figures in parenthesis refer to "Literature Cited," p. 355.
[4]Private communication from C. D. Jefferies.

TABLE 2.—*Effect of container upon nitrification, using soils of varying nitrate content obtained from previous experiment* (*Table 1*).

Initial nitrate nitrogen in p.p.m.	Net gain or loss nitrate nitrogen in p.p.m.					
	Soil		Soil + tobacco leaves			
	Card-board + asphaltum paint	Glass	Card-board + 2 coats of wax	Card-board + asphaltum paint	Glass	Glass coated inside with wax
2.2	—	79.3	8.0	5.4	115.1	4.2
21.2	—	55.1	30.8	12.3	98.4	—17.5
77.1	—29.4	40.7	—12.1	— 1.6	104.8	—72.0
63.9	—	—	—11.8*	—	42.3*	—
69.2	—	—	—	92.4*	104.9*	—

*Quart cardboard ice cream containers and glass fruit jars. All other containers were either ¼ pint cardboard containers or jelly glasses.

STUDIES IN THE SUMMER OF 1934

LOCALITIES SAMPLED

In the season of 1934 samples were taken in the period between April 28 and May 10. Effort was made to select localities representative of a fairly wide range of conditions and some which were of special interest for one reason or another. The locality descriptions follow.

Abbreviation	Description
A — Woodb. R. P. Mull	Woodbridge, red pine (*Pinus resinosa*)[5] plantation; age 19 ± years; good growth; fine crumb mull; Hartford fine sandy loam, gravelly phase.
B — Rain. R. P. Ck.	Rainbow, red pine plantation; block 22, age 36 years; slow growth; Merrimac coarse sand; untreated.
C — Rain. R. P. Limed	Same location. Limed plat.
D — Rain. R. P. Thick duff	Same location. Duff layer is maintained at 3 times the normal thickness. Otherwise the same as B.
E — Rain. W. P. Ck.	Rainbow, white pine (*Pinus strobus*) plantation; block 25; age 36 years; slow growth.
F — Rain. W. P. Limed	Same location. Limed plat.
G — Rain. Gray birch	Rainbow block 18; mostly gray birch (*Betula populifolia*), 2 to 4 inch dia., underplanted with pine.
H — Wind. Mat. W. P.	Windsor, Granby Rd., mature white pine 10 to 15 inches d. b. h. on Merrimac loamy sand. Raw humus.

[5]According to Gray's *Manual*. Ed. 7.

Abbreviation	Description
I — Wind. Young hdws.	Same location as H. Young hardwoods in an opening in the white pine.
J — E. Granby hdws. Podzol	East Granby. Hardwood stand of white oak (*Quercus alba*), red oak (*Quercus rubra*), maple (*Acer sp.*), ash (*Fraxinus sp.*), and cherry (*Prunus sp.*). Merrimac sand. Raw humus over a thin podzol layer.
K — Peoples Forest Mat. W. P.	Peoples Forest. Mature white pine 18 inch d. b. h. on terrace on side of valley. Merrimac sand.
L — N. Cole. Mat. W. P.	North Colebrook. Mature white pine 12 to 18 inches and larger. Level to moderate slope S.
M — Litch. Mat. Hem.-hdws.	Litchfield. Mature hemlock (*Tsuga canadensis*)—hardwoods 12 to 24 inches d. b. h., level, poorly drained muck soil.
N — Litch. Mat. Hem.-hdws.	Litchfield. Hemlock-hardwoods 12 to 24 inches. Higher ground, better drainage, no muck.
O — Litch. Bot.-land hdws. Muck	Litchfield. Bottom-land hardwoods. Poorly drained muck; north side of road. White oak, red maple (*Acer rubrum*), red oak, beech (*Fagus grandifolia*), chestnut (*Castanea dentata*).
P — Litch. Bot.-land hdws.	Litchfield. Hardwoods. South side of road; slightly higher ground, no muck. White oak, red oak.
Q — Beseck hdws. Mull	Beseck, Middlefield. Fast growing hardwoods, excellent mull. Good moisture conditions due to seepage from adjacent hill. Cheshire fine sandy loam to loam.
R — Mt. C. hdws. Mull	Mt. Carmel. Good hardwood stand 6 to 15 inches d. b. h. Red oak, white oak, beech, hickory (*Carya sp.*), red maple, dogwood (*Cornus florida*), occasional small hemlock. Wethersfield fine sandy loam.
S — Bethany. hdws. Raw humus	Bethany. Slow growing hardwoods, mostly scarlet oak (*Quercus coccinea*) and chestnut oak (*Quercus prinus*). Thick raw humus. Gloucester fine sandy loam.
T — Rain. R. P. Poor	Rainbow, Block 57. Young red pine stand exhibiting poor growth (12th to 14th row away from adjoining locust plat).
U — Rain. Locust	Rainbow, Block 58. Planted to black locust (*Robinia psuedoacacia*) 1903, cut 1923; sprout growth cut 1933. Adjoins block 57.

RESULTS OBTAINED

Total soluble nitrogen.—The quantitative measurements for ammonia and nitrate nitrogen in the mineral soil obtained at the end of the 3-month incubation period are presented graphically in Fig. 2. The samples are arranged in order of decreasing amounts of total soluble nitrogen (sum of ammonia and nitrate nitrogen) and at the same time the amount of each constituent is shown. The outstanding nitrifying samples were from localities A and Q, both excellent mull

types, the locust plat, U, and a limed white pine plat, F. The samples showing the greatest amount of ammonia were the more mature white pine and hemlock-hardwood stands in which there was a considerable accumulation of duff. Vigorous ammonification occurred also in the soil underlying the triple thickness of duff in the 36-year-old stand of red pine (D). It should be noted that the humus types produce just as much soluble nitrogen as do the mulls, but in the former case it occurs as ammonia rather than nitrates.

The data from the limed and unlimed plats at Rainbow show that under white pine, lime not only reduced the formation of ammonia but favored the accumulation of nitrates (compare F with E). Under red pine, on the other hand, lime reduced the ammonia without having had any apparent effect upon nitrates (compare B and C). These results are in agreement with previous tests (2) made on samples from the same plats, and may be explained in part, at least, by the differences in the C-N ratios which are as follows:

	C-N ratios	
	White pine plat	Red pine plat
F	42.0	53.2
A_1	24.7	32.3
A_2	24.0	23.7

Net gain in soluble nitrogen.—The results of spot plate tests made at the initiation and conclusion of the incubation period are presented in Fig. 3 and include data from both the duff and mineral layers. However, the order of arrangement is based upon the decreasing amounts of total soluble nitrogen in the mineral horizon as in Fig. 2. The cross-hatched blocks on the NH_3 nitrogen side indicate a loss in ammonia to the extent shown. There were no losses in nitrate nitrogen. The values shown for the duff samples should be multiplied by 2.

Owing to the nature of the tests, less reliance can be placed upon the absolute values obtained, but on the whole a general agreement can be seen between these results and those shown in Fig. 2. The mineral samples that contained the largest amount of nitrates at the end of the period also made the greatest net gain in nitrates, although the order is not necessarily the same. A like comparison can be made with respect to ammonia.

In the case of the duff samples, except for the locust plat and the limed white pine plat, very little nitrate nitrogen was found. On the other hand, large increases in ammonia occurred in the raw humus and podzol types and under the more mature white pine and hemlock-hardwood stands. It is interesting to note that soil from the mature white pine at Windsor (H) showed a smaller gain in ammonia and a larger gain in nitrate than did the samples taken under young hardwoods (I) growing in an opening in this same white pine stand, although the hardwood soil was less acid (pH 4.7) than the pine soil (pH 4.3).

Effect of locust trees.—The beneficial influence of locust trees reported by McIntyre and Jefferies (3), Chapman (1), and others is revealed here in the superior nitrifying ability of the soil from locality U in comparison with that from an adjoining young red pine stand (T). This is in direct confirmation of the behavior of the trees in the field. The plat next to the locust plat was planted in 1924 with 2-year red pine seedlings spaced 8 x 8 feet. At the present time the first

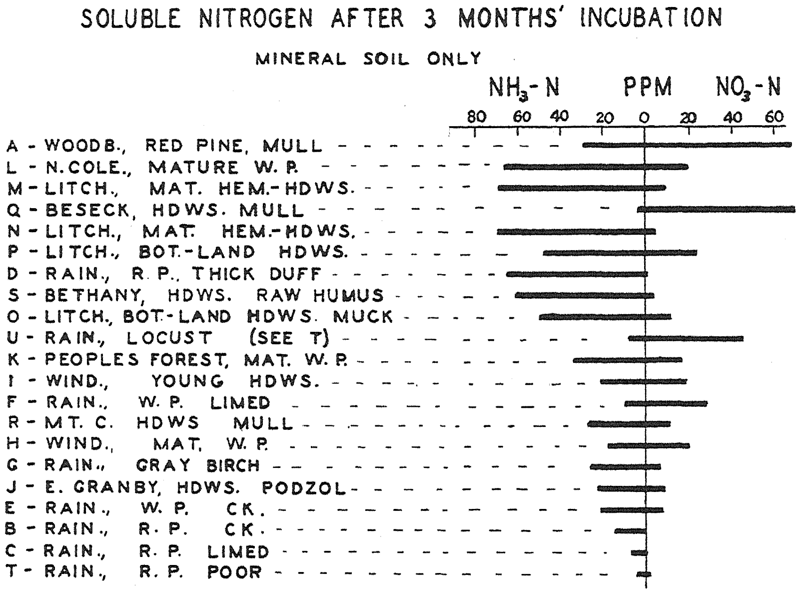

FIG. 2.—Amounts of ammonia and nitrate nitrogen in mineral soil samples after 3 months' incubation arranged in order of decreasing amounts of total soluble nitrogen.

three or four rows next to the locust are approximately 8 to 12 feet tall, while those farthest away—12 to 14 rows— are only 3 to 4 feet tall, with a definite gradation in between. Analysis of the soil has not revealed any difference in reaction or in total nitrogen in the soil under the tall trees as compared with that under the short trees. So far no soil characteristics aside from improved nitrifying ability have been found by laboratory tests which could account for the superior growth of the trees nearest the locust plat.

That tree growth and intensity of nitrification are closely correlated on the plat in question is further substantiated by the results of an incubation study made in the fall of 1933 in which case soil samples were collected from (a) the region of good tree growth, rows 1 and 2 (nearest the locust plat); (b) the region of medium growth, rows 7 to 9; and (c) the region of poor growth, rows 12 to 14. The soils were incubated 3 months with and without the addition of ground dried tobacco leaves (used at the rate of 0.2 gram per 100

grams of soil). The results, shown in Table 3, leave no doubt as to the relative nitrifying capacity of the soil from the several locations. Of particular interest is the accumulation of ammonia in the poor soil when treated with tobacco leaves. For some reason the ammonia was not oxidized into nitrates.

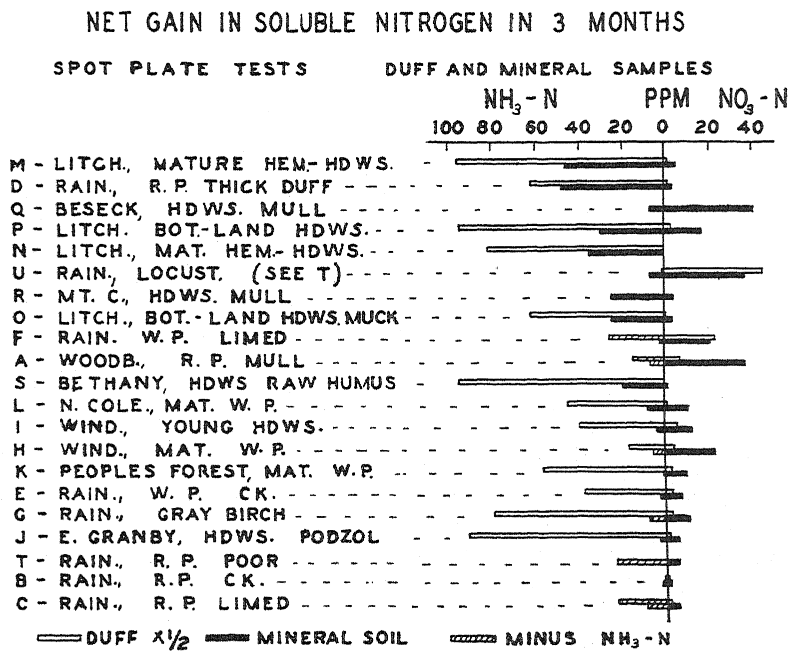

FIG. 3.—Net gain in ammonia and nitrate nitrogen in duff and mineral soil samples after 3 months' incubation arranged in order of decreasing amount of gain in the mineral samples. Values for duff material should be multiplied by 2.

TABLE 3.—*Nitrogen transformation in soil from a red pine plantation, Rainbow, incubation period 3 months.*

Approximate distance from locust plat, feet	Relative growth of red pine trees	NH_3 nitrogen, p.p.m.			NO_3 nitrogen, p.p.m.		
		Initial	Final	Gain or loss	Initial	Final	Gain
			Soil Only				
8–16	Good	0	1.1	1.1	0	20.2	20.2
64	Medium	10	0	—0.10	Trace	1.3	1.3
108	Poor	0	1.4	1.4	0	0	0
			Soil Plus Tobacco Leaves				
8–16	Good	0	0	0	0	69.3	69.3
64	Medium	10	22.2	12.2	0	32.3	32.3
108	Poor	0	42.2	42.2	0	8.1	8.1

Correlations with soil reaction.—Soil reaction was estimated by the spot plate test before and after incubation. Considering the samples as a whole there was practically no correlation with pH nor with change in pH during the incubation period. The mean pH value of all the duff samples was 4.60 before and 4.67 after incubation; and of the mineral soil, 4.57 before and 4.50 after.

However, upon re-grouping the samples upon the basis of gain in either ammonia or nitrates and keeping the duff and mineral samples separate, we find the correlations shown in Table 4. In the duff material there is a correlation, on the one hand, between ammonia nitrogen increase and pH values before incubation and particularly with change in pH. The more acid the initial reaction the greater the amount of ammonia nitrogen formed and the greater the change in pH toward the alkaline side. On the other hand, high nitrate formation is associated with a higher initial pH and a greater change toward a more acid condition than where little or no nitrates are formed.

TABLE 4.—*Correlation of nitrogen transformation with pH.*

Duff Samples					
Av. gain or loss in NH_3 N, p.p.m.	—43	—2.5	70	121	181
Av. pH: Initial	6.27	4.50	4.33	4.07	4.14
Final	5.90	4.20	4.45	4.30	4.55
Change	—0.37	—0.30	+0.12	+0.23	+0.41
Av. gain or loss in NO_3 N, p.p.m.	0	2.8	8.1	68	—
Av. pH: Initial	3.76	4.26	4.60	5.70	—
Final	4.43	4.26	4.59	5.45	—
Change	+0.67	0	—0.01	—0.25	—
Mineral Samples					
Ave. gain or loss in NH_3 N, p.p.m.	—19	—5.8	4.2	25	43
Av. pH: Initial	4.70	4.71	4.56	4.50	4.33
Final	4.65	4.43	4.58	4.55	4.37
Change	—0.05	—0.28	+0.02	+0.05	+0.04

Correlations with other constituents.—Attempts were made to correlate nitrogen transformation with other constituents determined by the spot plate test, namely phosphorus, potassium, calcium, and aluminum. A correlation between ammonia nitrogen and potassium was found, but it is of little consequence because of the interference of ammonia with the potassium test. This test is reliable only when there is little or no ammonia present. In a very general way there is a correlation between nitrogen transformation and calcium content in that a large amount of calcium accompanies a low ammonia and a high nitrate accumulation. No other relationships were discernible.

DISCUSSION

On the whole the results of these incubation studies are in accord with those usually obtained with forest soils of similar nature. The

data obtained serve to confirm the previous findings of the author (2) and others reported by him, rather than to contribute anything particularly new.

The experiment does demonstrate, however, that the procedure followed in this study is satisfactory, and the writer feels it is basically sound both in theory and practice. It is believed that the lower values obtained, in no case exceeding 200 p.p.m., are more in keeping with the amount of soluble nitrogen in the forest than are the much higher values usually obtained, ranging up to 3,000 and more p.p.m., where the samples are incubated under "optimum" conditions. In other words, except in special cases, the investigator should attempt to simulate *natural* conditions as far as practical rather than to use *optimum* conditions.

SUMMARY AND CONCLUSIONS

A modification in the procedure for sampling and incubating soils is proposed for use primarily in forest soil studies. The essential features of this new procedure are (a) sampling about May 1 with a soil cylinder or tube which cuts out a core of the upper 6 or 8 inches with very little disturbance and (b) incubating this sample out of doors subject to the natural temperature changes but not exposed to the direct sunlight.

Glass containers were the most satisfactory. Cardboard, whether paraffined or not, greatly interfered with the accumulation of soluble nitrogen and should not be used.

The results of studies carried on with samples from a rather wide range of forest conditions may be generalized as follows:

1. The mull types found in fast-growing hardwood stands nitrify to a considerable degree with the formation of only a relatively small amount of ammonia.

2. The greatest ammonia accumulation occurred in the thick duff found in mature hemlock-hardwood and mature white pine stands.

3. Lime stimulated nitrification in the soil from a white pine plantation but had little effect in a red pine plantation.

4. Soil from a locust stand nitrified to a marked degree and was in extreme contrast in this respect to a young red pine plantation adjoining. Growth of the red pine trees is directly correlated with the nitrifying capacity of the soil.

5. In general, there is an inverse relation between ammonia accumulation and initial acidity and a direct relation between nitrate accumulation and initial acidity. The change in reaction during the incubation period was toward a lesser acidity where ammonification was greatest and toward a stronger acidity where nitrification was greatest.

6. There was no correlation between nitrogen transformation and the amount of other soil constituents as determined by the spot plate method.

7. The procedure followed has proved satisfactory and the results obtained are believed to be more nearly in keeping with nitrogen changes in the natural forest soil than are those obtained under artificial optimum conditions.

LITERATURE CITED

1. CHAPMAN, ARTHUR GLENN. The effect of black locust on associated species with special reference to forest trees. Amer. Soil Survey Assoc. Bul., 15 : 39–41. 1934.
2. LUNT, HERBERT A. Profile characteristics of New England forest soils. Conn. Agr. Exp. Sta. Bul. 342. 1932.
3. McINTYRE, A. C., and JEFFERIES, C. D. The effect of black locust on soil nitrogen and growth of catalpa. Jour. For., 30 : 22–28. 1932.
4. MORGAN, M. F. Microchemical soil tests. Conn. Agr. Exp. Sta. Bul. 333. 1932.

NITRIFICATION IN THE GRUNDY SILT LOAM AS INFLUENCED BY LIMING[1]

R. H. WALKER AND P. E. BROWN[2]

NUMEROUS experiments have shown that liming acid soils influences their physical, chemical, and bacteriological properties. In studying the effects of liming on the Grundy silt loam in southern Iowa attention has been given to certain chemical and bacteriological effects. The data obtained in the chemical studies have been reported previously (6, 7)[3]. This paper presents the results of one phase of the bacteriological studies made on this soil, namely, the influence of liming on nitrification.

Inasmuch as the nitrifying power of soils has been shown to be closely related to the pH or the buffer capacity, and that it is also rather closely related to or correlated with the crop-producing power, nitrification studies have been made as indicating the influence of liming, not only on a specific physiological group of soil microorganisms, but as suggesting the influence of lime on microbiological activities of soils in general.

EXPERIMENTAL

Grundy silt loam (3) is the most extensively developed upland soil in southern Iowa. It is of loessial origin, dark brown to black in color, and has a rather compact or impervious subsoil. When properly managed this soil is very productive and it may be classed as one of the more fertile soils of Iowa. On most farms, however, the yields of crops are not as large as they should be due mainly to the fact that the soil is strongly acid and in need of lime. This conclusion is supported by the results of previous experiments (3, 4, 5).

Limestone was applied in different amounts and degrees of fineness to one-tenth acre plats of Grundy silt loam in June 1929. Quarry-run limestone was applied at rates of 1, 2, 3, 4, 5, and 6 tons per acre, and limestones of different degrees of fineness employed, namely, 20-mesh, 40-mesh, and 100-mesh, were applied at the rate of 3 tons per acre. A plat treated with hydrated lime in an amount equivalent in CaO content to 3 tons of the limestone was also included in the experiment for comparative purposes. Other plats were left untreated to serve as checks.

The soil of these variously limed plats was sampled from time to time during a period of 5 years, and the nitrifying power was determined. For the determination 30 mgm of N as ammonium sulfate were added to 100 grams (oven-dry basis) of fresh moist soil. The soils were then incubated in covered tumblers at near optimum moisture content and at room temperature for 4 weeks, after which the nitrate content was determined by the phenoldisulfonic acid method.

The hydrogen-ion concentration of the soils was determined potentiometrically by means of the quinhydrone electrode. The results of these determinations have been published elsewhere (6), but some of the data will be included here, inas-

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[2]Research Associate Professor in Soils and Head of Department, respectively.
[3]Figures in parenthesis refer to "Literature Cited," p. 363.

much as a rather close relationship has been shown between the pH and the nitrifying power of these variously limed soils.

RESULTS

EFFECTS OF DIFFERENT AMOUNTS OF LIMESTONE

The first samples were taken 1 month after the limestone was applied. The pH of the soil and the amounts of nitrate nitrogen produced in the nitrification tests on these samples are shown graphically in Fig. 1. It may be observed that the limestone had exerted an appreciable effect on the hydrogen-ion concentration of the soil during the first month, the increase in pH being a function of the amount of limestone applied. In general, this was also true of the nitrifying power. With one exception each additional ton of limestone applied gave a further increase in the nitrifying power of the soil. The changes in nitrifying power appear to be associated directly with the changes in hydrogen-ion concentration. It is entirely possible, although it is not proved in this work, that the changes in nitrifying power resulted directly from changes in the hydrogen-ion concentration effected by the limestone.

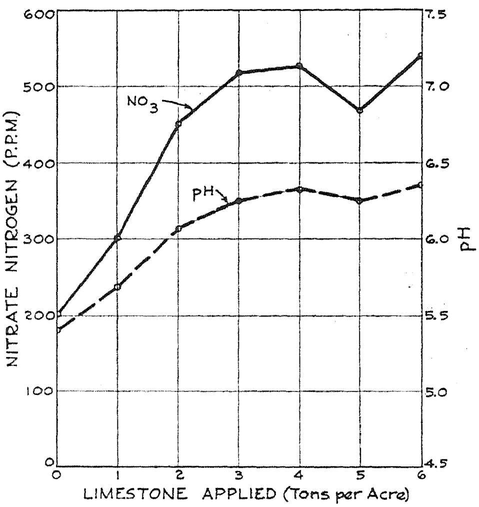

FIG. 1.—Nitrifying power and pH of Grundy silt loam 1 month after liming.

The results of the determinations of nitrifying power at other sampling dates were similar to those obtained at the first sampling. The data obtained in this and in all the subsequent tests are shown in Table 1. From a study of these data it is apparent that the application of limestone to this soil led to an increased nitrifying power, the increase being a function of the amount of limestone applied.

It may be observed, however, that there was considerable variation in the nitrifying power of the soil of a particular plat at different times of the year and in different years. Because of this fact a statistical analysis of the data was made by the analysis of variance method suggested by Fisher (1) and described by Snedecor (2). The analysis is shown in Table 2.

This analysis indicates that if the data as a whole are considered, the differences in nitrifying power between the differently treated soils are very highly significant. The differences in nitrifying power between sampling dates are also very highly significant. Inasmuch as this is the case, and since it was purposed to determine as definitely

as possible the effects of different amounts of limestone on the nitrifying power of this soil, the statistical analysis was carried a step further. The significance of the differences between the mean nitrifying power of the variously limed soils was determined. The lowest mean difference between treatments to be significant or highly significant, corresponding to Fisher's 5% and 1% points, respectively, was calculated as follows: M.D. = $\sigma_{M.D.} \times t$.

TABLE 1.—*Nitrate nitrogen in p.p.m. produced in nitrification tests on Grundy silt loam treated with different amounts of quarry-run limestone in the field.*

Date of sampling	No lime	1 ton lime	2 tons lime	3 tons lime	4 tons lime	5 tons lime	6 tons lime
1929							
July 11	203	302	452	518	527	468	541
Aug. 12	136	196	508	559	879	697	774
Sept. 18	70	117	157	197	235	258	267
Oct. 14	71	91	143	173	228	228	237
1930							
Mar. 29	117	216	250	285	266	266	281
June 17	115	146	161	157	167	151	202
Sept. 18	143	182	173	218	197	199	222
Oct. 15	113	145	159	165	193	206	214
1931							
Apr. 6	160	190	206	173	202	205	228
May 20	179	220	232	231	231	237	226
July 16	130	157	175	190	192	198	210
Oct. 19	96	157	184	186	217	239	299
1932							
June 16	173	179	185	193	191	199	202
Oct. 1	56	102	138	173	197	194	206
1933							
May 16	88	118	114	140	182	196	191
Nov. 4	108	134	158	200	228	228	222

TABLE 2.—*Analysis of variance of nitrifying power of Grundy silt loam treated with different amounts of quarry-run limestone.*

Source of variation	d/f	Sum of squares	Mean square
Total	111	19,168	—
Between treatments	6	3,340	556.6**
Between dates	15	11,966	797.7**
Remainder	90	3,862	42.9

**Highly significant.

In this particular case the standard deviation of the mean difference, $\sigma_{M.D.}$, equals 23,156 and t equals 2.042 and 2.750 for the 5% and 1% points, respectively. Thus, the lowest mean difference, M.D., in nitrifying power between two plats to be significant is 47.284, and to be highly significant is 63.679.

The mean nitrifying power of the various soils for the 5-year period was as follows: No lime, 123.1; 1 ton, 166.2; 2 tons, 211.9; 3 tons, 234.3; 4 tons, 271.9; 5 tons, 261.9; and 6 tons, 282.5. Hence, the mean difference in nitrifying power between any two plats treated with limestone in amounts differing by only 1 ton per acre was not quite significant. The mean difference in nitrifying power between the check soil which received no limestone and the soil treated with 2 tons of limestone was highly significant, however. The difference resulting from applications of 2 and 4 tons of limestone was significant, but not quite highly significant. Hence, where limestone was applied up to 4 tons per acre, the increase in nitrifying power induced per ton of limestone was not significant, but the increases induced by 2-ton additions of limestone were significant.

Where larger applications of limestone were made, 2 tons additional of limestone did not give, in all cases, a significant increase in nitrifying power. For example, the increase in nitrifying power of the 5-ton treated soil over the 3-ton treated soil, although appreciable, was not quite large enough to be significant of heterogeneity. Similarly, the increase in nitrifying power of the 6-ton treated soil over the 4-ton treated soil was not significant. The increases in nitrifying power effected by the 5-ton treatment over the 2-ton treatment and by the 6-ton over the 3-ton treatment, a difference of 3 tons of limestone in each case, were highly significant.

These comparisons show that where limestone was applied in amounts less than the lime requirement of the soil or slightly above, the mean increases in nitrifying power induced by 1-ton additional applications of limestone were comparatively large and rather consistent, but they were not quite large enough to be significant. Two-ton increases in amounts of limestone applied, however, induced such large increases in nitrifying power that they were significant or highly significant in each case. Where limestone was applied in amounts beyond the lime requirement of the soil the increase in nitrifying power induced per unit of limestone was reduced somewhat, and larger additional amounts were found necessary to bring about significant increases in nitrifying power.

The above analysis was based upon the results obtained over the entire 5-year period. Although the increases in nitrifying power induced by 1-ton additional amounts of limestone did not prove significant, they were rather large in most cases and undoubtedly they are of real importance. Furthermore, it is very probable that these differences are sufficiently large to have proved significant had there been enough replicate samples taken to warrant a statistical analysis of the data for each date of sampling. There was a rather consistent trend in the changes in nitrifying power, there being an increase in most cases with each additional ton of limestone. Fig. 1 illustrates this point.

The mean nitrifying power for the entire 5-year period has been plotted against the amounts of limestone applied, and the graph is shown in Fig. 2. Thus the data as a whole indicate that there was a rather consistent increase in nitrifying power of this soil induced by additional amounts of limestone applied up to 6 tons per acre, the

largest amount applied. The largest increases induced per ton of limestone occurred with the smaller applications and up to or slightly above the lime requirement of the soil, which was from 3 to 3½ tons per acre. Above this amount the increases in nitrifying power effected per ton of limestone were not so large.

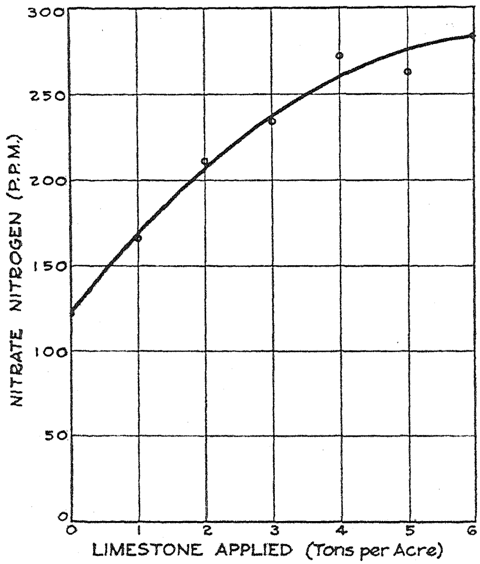

FIG. 2.—The mean nitrifying power of Grundy silt loam treated with different amounts of quarry-run limestone.

EFFECTS OF LIMESTONES OF DIFFERENT DEGREES OF FINENESS AND OF HYDRATED LIME

The plats treated with limestones of different degrees of fineness and with hydrated lime were sampled at the same time as the other plats and the nitrifying power of the soils was determined in the same manner. The results of these tests are shown in Table 3. These data were also analyzed statistically by the variance method and the analysis is shown in Table 4.

The analysis shows that if the results of all the determinations for the entire 5-year period are considered as a whole, the differences in nitrifying power of the differently treated soils are significant. It is also shown that the differences in nitrifying power of the variously treated soils at different samplings are highly significant.

Further statistical analysis was made to determine the significance of the differences between the mean nitrifying power of the variously limed soils. The method was the same as that described above. The analysis revealed the fact that, although the soil treated with 20-mesh limestone showed a higher mean nitrifying power than did the soil treated with quarry-run limestone, the increase was not significant. Similarly, the increases in nitrifying power induced by the 40- and 100-mesh limestones over that brought about by the quarry-run limestone were each too small to be significant, although they were real. The hydrated lime, however, effected a highly significant increase in nitrifying power over that brought about by the quarry-run limestone. Furthermore, the hydrated lime gave a highly significant and a significant increase in nitrifying power over that induced by the 20- and 100-mesh limestones, respectively. The increase in nitrifying power of the hydrated lime treated soil over the soil treated with 40-mesh limestone was apparent, but it was not large enough to be significant.

TABLE 3.—*Nitrate nitrogen in p.p.m. produced in nitrification tests on Grundy silt loam treated with limestones of different degrees of fineness and with hydrated lime.*

Date of sampling	Degree of fineness of limestone				Hydrated lime
	Quarry-run	20-mesh	40-mesh	100-mesh	
1929					
July 11	518	519	528	533	562
Aug. 12	559	558	467	380	801
Sept. 18	197	155	264	249	291
Oct. 14	173	186	242	224	254
1930					
Mar. 29	285	251	275	281	266
June 17	157	192	202	227	196
Sept. 18	218	221	225	225	227
Oct. 15	165	226	232	238	255
1931					
April 6	173	224	223	219	220
May 20	231	217	226	233	234
July 16	190	184	225	226	247
Oct. 19	186	138	255	215	201
1932					
June 16	193	188	195	193	187
Oct. 1	173	129	169	189	202
1933					
May 16	140	182	184	161	178
Nov. 4	200	228	192	165	183

TABLE 4.—*Analysis of variance of nitrifying power of Grundy silt loam treated with limestones of different degrees of fineness and with hydrated lime.*

Source of variation	d/f	Sum of squares	Mean square
Total	79	11,613	——
Between treatments	4	231	57.7*
Between dates	15	10,181	678.0**
Remainder	60	1,201	20.0

*Significant.
**Highly significant.

Although the differences in the mean nitrifying power of certain lime-treated soils were large enough to be significant and others were not, the nitrifying power of the variously treated soils was rather uniform. This fact is illustrated in Fig. 3.

This is what would be expected naturally, inasmuch as the different limestones and hydrated lime were applied in quantities supplying the same amounts of CaO, and the results were obtained in studies conducted over a 5-year period after the lime had been applied. It is logical to assume that the finer limestones would react more quickly with the acids of the soil than would the coarser materials, but over a period of 5 years the coarser limestones would undoubtedly react

sufficiently to increase the pH of the soil to almost the same extent as the finer limestones. This was found to be the case, as previously reported (6). Hence, it is equally logical to assume that for a short period of time after the lime was applied, the nitrifying power of the soil treated with the finer grades of limestone would be higher than that of the soils treated with the coarser limestones. Furthermore, it is reasonable to assume that changes in the nitrifying power would correspond to changes in pH. Hence, comparisons of the mean nitrifying power in studies made over a period of 5 years may be expected to show smaller differences between means for soil treated with limestones of different degrees of fineness applied in equal amounts than for soils treated with quarry-run material but applied in different amounts.

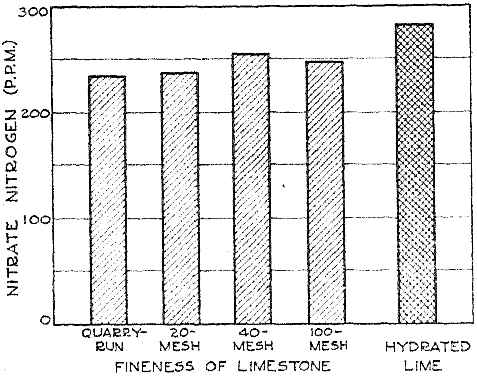

FIG. 3.—The mean nitrifying power of Grundy silt loam treated with limestones of different degrees of fineness and with hydrated lime.

The statistical analysis in Table 4 shows that there was a significant difference in nitrifying power of the variously treated soils at different sampling dates. A study of the mean nitrifying power of the soil of all plats at different dates indicates that there was a rather definite decrease during the period in which they were under observation. If the mean nitrifying power of the variously treated soils per year is considered, it may be observed that 388 p.p.m. of nitrate nitrogen were produced in 1929, 228 in 1930, 213 in 1931, 182 in 1932, and 180 in 1933.

SUMMARY AND CONCLUSIONS

1. Plats of Grundy silt loam were treated with different amounts of quarry-run limestone, with limestones of different degrees of fineness, and with hydrated lime. The soil of these plats was sampled frequently over a period of 5 years and its nitrifying power was determined.

2. The limestones and hydrated lime exerted an appreciable effect on the pH and also the nitrifying power of the soil. The changes in nitrifying power appeared to be associated directly with the changes in hydrogen-ion concentration, these changes being, to a certain extent, a function of the amount of limestone, or of the degree of fineness of the limestone applied.

3. The data were analyzed statistically to determine the significance of the differences in nitrifying power of the variously treated soils. This analysis shows that where limestone was applied in amounts less than the lime requirement of the soil or slightly above, the mean increases in nitrifying power induced by 1-ton additional

applications of limestone were comparatively large and rather consistent, but they were not quite large enough to be significant.

4. Two-ton increases in amounts of limestone applied, induced such large increases in nitrifying power that they were significant or highly significant in each case.

5. Where limestone was applied in amounts beyond the lime requirement of the soil, the increase in nitrifying power induced per unit of limestone was reduced somewhat, and larger additional amounts were found necessary to bring about significant increases in nitrifying power.

6. The 5-year means of the nitrifying power of soils treated with equal amounts of quarry-run, 20-mesh, 40-mesh, and 100-mesh limestones were comparatively uniform, and all except that for the 40-mesh limestone were significantly lower than that for the hydrated lime. The mean difference in nitrifying power between the 40-mesh and hydrated lime treated soils lacked only a very small amount of being significant statistically.

LITERATURE CITED

1. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh : Oliver and Boyd. Ed. 4. 1932.
2. SNEDECOR, GEORGE W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa : Collegiate Press, Inc. 1934.
3. STEVENSON, W. H., BROWN, P. E., *et al.* A soil management program for Grundy silt loam. Ia. Agr. Exp. Sta. Bul. 280. 1931.
4. WALKER, R. H., and BROWN, P. E. Effects of inoculation and liming on soybeans grown on the Grundy silt loam. Ia. Agr. Exp. Sta. Bul. 298. 1933.
5. ———, ———. Effects of inoculation and liming on alfalfa grown on the Grundy silt loam. Ia. Agr. Exp. Sta. Bul. 305. 1933.
6. ———, ———. The effects of lime on the hydrogen-ion concentration and base exchange complex of Grundy silt loam. Ia. Agr. Exp. Sta. Res. Bul. 178. 1935.
7. ———, ———, and YOUNG, A. W. Some chemical and bacteriological effects of various kinds and amounts of lime on certain southern Iowa soils. Part I. Laboratory and greenhouse experiments. Ia. Agr. Exp. Sta. Res. Bul. 148. 1932.

VARIETAL SURVIVAL OF ALFALFA ON WILT-INFESTED SOIL[1]

L. F. GRABER AND F. R. JONES[2]

THE duration of productivity of established fields of alfalfa on fertile soil in Wisconsin is influenced largely by winter injury, and especially in the southern and western parts of the state, by the bacterial wilt disease caused by *Phytomonas insidiosa*. Winter killing or injury is due, primarily, to climatic conditions and after seeding it may occur during the late fall, winter, or early spring period of any year. Bacterial wilt occasionally destroys a field in a single summer, but usually it develops progressively, reducing the plant population below a profitable level after the third cutting year.

When wilt and winter injury are associated in thinning stands it is difficult to distinguish the degree of loss occasioned by each. As an aid in appraising the losses resulting from these two enemies of the alfalfa plant from the standpoint of survival value under Wisconsin conditions, a field comparison was made of strains of generally known wilt and winter resistance.

PLAN OF EXPERIMENT

The trial was conducted on wilt-infested rolling (Carrington) silt loam soil in Green County, Wis. Alfalfa had been grown in this locality for some 30 years and it is reported that at first stands survived 8 to 10 years. However, since 1925, when bacterial wilt was found thoroughly distributed, stands have not remained productive after the third cutting year.

The soil (3 acres) was properly limed and fertilized with phosphate fertilizer. The area was divided into plats. Two of these were long and parallel strips 4 rods apart, 2 rods wide, and 64 rods long. One of these was sown with winter-hardy and wilt-resistant Ladak alfalfa; the other to winter-hardy and wilt-resistant Imported Turkistan. Between and bordering these two long check plats, eight plats (4 rods x 8 rods, except one 4 rods x 5½ rods) were marked out and sown with wilt-susceptible strains of varying degrees of winter resistance, as follows: Grimm (1 plat), Cossack (1 plat), Canadian variegated (2 plats), Montana common (2 plats), and South Dakota common (2 plats). Each of these plats was separated one from another by a 6-foot alley which was seeded with timothy and clover. The seed used was believed to be fairly representative of these varieties and strains, and all seedings were made on April 14, 1929. Thick and uniform stands of alfalfa were established, and after 1929 the plants were cut under a field schedule of two cuttings annually. No yields were taken, but beginning in April, 1931, when the plants were quite free from winter injury and before symptoms of wilt had appeared, counts of the number of plants on unit areas of $\frac{1}{20,000}$ acre in each plat, were taken at various intervals of time (Table 1). The number of individual counts made at any one time varied with the condition of each plat, consideration being given to any irregularity in stand that had developed.

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WILT INFECTION IN THIRD YEAR

In the late summer of 1931 wilt appeared in all of the plats, though very sparsely in Ladak and Turkistan. During the following winter, plants sustained severe injury for the first time and a marked reduction in stand was recorded by the counts. Nearly all plants, even of Turkistan, showed dead tissue about the base of the crowns, and during a hot dry period in the spring far more plants appeared to die from a drying out of these injured crowns that from wilt, which up to that time did not appear to have caused much loss except in a few small areas. While the winter damage appeared to have been fairly uniform over the entire area, the stands were still in a good productive condition in June, 1932, except in one plat of Montana common. Rapid declines in stand occurred during the summer and fall of 1932 and these appeared to be due largely to the death of plants infected with bacterial wilt. Only Turkistan, Ladak, and Cossack maintained gcod stands. Grimm and Canadian variegated had a higher survival of plants than the Montana and South Dakota commons, but in the following year they also became very unproductive.

TABLE 1.—*Field losses of alfalfa plants in thickly established stands of several varieties seeded April 14, 1929, on wilt-infested soil.*

Kind	No. plats	Number of live plants on 1/20,000 acre (2.178 sq. ft.)						Condition of stand on July 21, 1934
		Apr. 18, 1931	June 29, 1932	Oct. 31, 1932	Apr. 26, 1933	Oct. 10, 1933	July 21, 1934	
Ladak........	Check	58	23	15.2	13.7	9.2	8.8	Good
Imported Turkistan......	Check	62	23	15.6	13.1	9.0	9.2	Good
Cossack.......	1	65	31	14.0	8.4	8.0	4.4	Fair
Grimm........	1	60	18	7.7	2.7	1.0	0.6	Poor
Canadian variegated.......	2	61	21	9.4	3.5	1.5	0.5	Poor
Mont. common	2	54	11	6.8	1.1	0.6	0.6	Poor
S. Dak. common........	2	53	18	5.8	2.1	0.4	0.5	Poor

From October 31, 1932, to April 26, 1933, there was another severe loss of plants. The populations of the regional strains of Montana and South Dakota common decreased 84% and 64%, respectively, Grimm 65% Canadian variegated 63%, Cossack 40%, Turkistan 16% and Ladak 10% during this period. While the Ladak and this Turkistan were somewhat more hardy than Grimm and Canadian variegated, the difference was not sufficient to account for the almost complete loss of stand of the two latter varieties. Rather, it appears that the numerous wilt-infected plants of all the susceptible varieties in the fall of 1932 readily succumbed to the winter damage of 1932–33, while Ladak and Turkistan having relatively low infections were able to survive with but a small loss.

While Cossack alfalfa maintained a fair stand even in the fifth year (1934) of the trial, the plant population was less than half that of the Ladak and Turkistan immediately contiguous to it, and many of the plants were dwarfed by disease. Furthermore, disease determinations made from representative samples of these varieties showed that 60% of the Cossack population was infected in contrast with but 20% of the Ladak and Turkistan plants. That the superiority in survival in Cossack in comparison with Grimm and other wilt-susceptible strains in this instance is due to a degree of wilt resistance generally present in the variety appears unlikely from the result of artificial tests. The most extensive of these tests was made at Madison, Wis., in 1934, when 2,000 plants from 17 seed lots of Cossack of known origin were compared. Little difference was found between these lots and on the whole they were not decisively superior to Grimm. Yet, in a previous field trial of 6 years duration on the University Farm, Madison, Wis., another strain of Cossack alfalfa showed a moderately superior survival in comparison with Grimm and Canadian variegated. The reason for this field superiority with the two lots of Cossack alfalfa appears to lie in some character or combination of characters which can only be determined by further experiment. In the possession of qualities which make possible long survival of alfalfa, Ladak and Turkistan proved outstanding in the field test made on wilt-infested soil in Green County, Wis.

SUMMARY

To ascertain the influence of bacterial wilt disease caused by *Phytomonas insidiosa* in shortening the life of stands of alfalfa in southern Wisconsin, a field comparison was made of winter-hardy and wilt-resistant Ladak and Turkistan alfalfa with winter-hardy but wilt-susceptible Grimm, Canadian variegated, and Cossack alfalfa and with the regional strains of susceptible and moderately hardy Montana and South Dakota common alfalfa. All these strains were grown on wilt-infested soil. The field was cut twice annually for five consecutive years and the survival was ascertained by population counts. Wilt appeared in the summer and fall of the third year and all the susceptible varieties, except Cossack, were rapidly and almost completely eliminated by the disease and winter injury at the end of the third and fourth cutting years. Cossack, while severely diseased, proved intermediate in survival between the remainder of the susceptible varieties and the wilt-resistant sorts, but only the resistant Ladak and Imported Turkistan maintained good stands at the end of the fifth year. Wilt infection appeared to reduce the winter survival of such normally hardy and susceptible varieties as Grimm, Canadian variegated, and Cossack so that they appeared superficially like non-hardy sorts after infection.

THE PLACE OF LEGUMES IN PASTURE PRODUCTION[1]

E. N. Fergus[2]

SOME years ago Campbell[3] presented data which suggest that in eastern United States nature largely uses legumes for building up the nitrogen supply of newly exposed soils, and that as the available nitrogen supply becomes less of a limiting factor in the support of the plant population on a soil, the legumes become relatively much less prominent in the vegetation. It seems reasonable to infer, therefore, that legumes should naturally be present in the pasture flora in eastern United States where the permanent pasture is in reality a pre-climax plant community, and further that if they are present their effect, because of their nitrogen-fixing quality, tends to cause the pasture flora to change to an ecologically more advanced plant community.

However, such a change in flora destroys the desirable pasture community, consequently man must neutralize these forces by various practices available to him and thus hold the community more or less constant. Among these practices are fertilizing, liming, mowing, grubbing, and, of course, pasturing itself which probably is effective largely because of the indirect effects of the removal of fixed nitrogen.

If the combined dynamics of these practices balance the dynamics of progressive plant community succession, the flora will remain pracically constant; if stronger, they will force a regressive succession; if weaker, the succession will move slowly toward the climax plant community. Perhaps the contrary forces are never balanced and man must continually vary the intensity of modifiable environmental factors to accomplish this purpose. This is pasture management, the critical element in pasture production.

While we do not wish to imply that there are not other important factors in pasture production, we consider that, economically, the nitrogen supply is by far the most important. It may be, and probably usually is, impossible to grow good grass or legumes without the addition of lime, phosphorus, or potassium or all of them, but it is a comparatively simple matter to supply these deficiencies, and usually the expense is not great. But with mineral deficiencies corrected, the most difficult problem remains, *viz.*, that of supplying, utilizing, and conserving nitrogen.

There are two methods for supplying nitrogen, namely, by applying commercial carriers of the element and by providing for its fixation by legumes and micro-organisms. The value of the former method has not been proved sufficiently, largely because it has not been studied as a consistent practice in the management of permanent pastures. However, there is considerable evidence that its use is

[1]Contribution from the Department of Agronomy, Kentucky Agricultural Experiment Station, Lexington, Ky. Also presented at the annual meeting of the Society held in Washington, D. C., November 23, 1934. Published by permission of the Director. Received for publication February 18, 1935.

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[3]Campbell, Elmer. Wild legumes and soil fertility. Ecol., 8 : 480–483. 1927.

followed by the gradual disappearance of the legumes from the flora, especially if applications of the nitrogen carrier are large. This method of supplying nitrogen needs much study which takes into consideration all factors concerned with the permanency of desirable pasture floras and their economic utilization. The other method of supplying the nitrogen, namely, by natural fixation, likewise has not been sufficiently studied, but it has one important argument in its favor; it is nature's way of doing it. That means that the plant community, which is a natural community, is receiving its nitrogen in response to natural requirements rather than in response to man's desires, which, though admirable, may sometimes lead to practices that destroy rather than build.

Nature seems to have given an example of a satisfactory solution of the nitrogen problem in the ecology and productivity of pastures of long standing in the central bluegrass region of Kentucky where, because conditions are suitable for legumes, they not only supply sufficient nitrogen for productive pastures, but also constitute a highly valuable component of the pasture flora.

That legumes in a pasture provide nitrogen for the non-legume portion of the flora has been rather generally assumed, largely because of the known value of legumes in a rotation. However, some students have observed the effects of legumes on pasture production and consistently have sown legumes in pastures with the idea of improving them. Probably Prof. I. P. Roberts of Cornell University, who established the practice about 1883 on a pasture that bore his name, was first to do this.[4] It is significant that 35 years later he puts the maintenance of legumes in that pasture in the first position in enumerating four factors responsible for its high productivity.

As we have previously stated, nature has long been answering the question of the place of legumes in pasture production and improvement by her procedure in the bluegrass region of Kentucky. The soils are highly fertile, so fertile, in fact, that although cropped for over a hundred years they are still more productive even without the use of fertilizer or manure than are other soils of the state with the most effective soil treatments. Some conception of this productivity may be had from data in Table 1, giving the average corn yields for a 10-year period (1920–29) of the untreated plat on the Lexington soil field and of the highest yielding plat of each field representative of other large soil areas of the state.

Not only has the plat on the Lexington soil field received no manure or fertilizer, but it has had everything except the second clover crop removed. Yet, after 19 years of such farming, preceded by 11 years of general cropping after breaking out of an old sod, this plat still yields as well or better than other soils of the state which have received liberal liming, fertilizing and manuring.

The pastures of the bluegrass region, which, of course, do not constitute the natural climax vegetation of the area, consist almost wholly of Kentucky bluegrass and white clover. These plants are usually found together. One may be dominant one year and the other

[4]Roberts, I. P. The Roberts pasture. Cornell Univ. Agr. Exp. Sta. Bul. 280. 1910.

another year. If a pasture is closely grazed continuously, or even frequently, white clover is almost always present and usually widely distributed. If a pasture is always undergrazed, white clover is not present in appreciable amount except at wide intervals, when it may become quite prominent.

TABLE 1.—*Comparative analytical and yield data from certain plats of the soil experiment fields of Kentucky representative of major soil areas.*

Soil field	Plat treatment*	Corn yield in bu., 1920–29	Elements in 2,000,000 lbs. surface soil, lbs.			pH
			P	K	N	
Lexington	None	57.8	10,000	28,000	4,500	5.4
Mayfield	MLPK	58.0	960	29,700	1,920	4.9
Campbellsville	MLPKN	54.6	1,100	13,000	2,375	5.5
Berea	MLPK	51.5	800	19,000	2,200	4.5
Greenville	MLRPK	49.2	660	24,600	1,780	5.5
Fariston	LPK	44.4	820	24,400	2,300	4.5

*None = No lime, manure or fertilizer and all crop materials except second-crop clover removed; L = Ground limestone; P = Superphosphate; RP = Rock phosphate; K = Muriate of potash; N = Nitrate of soda; M = Barn manure throughout the period, except that at Campbellsville it was used 4 years out of 10, and at Greenville crop residues were used 5 years in lieu of manure. For a more detailed report of the treatment and yields of these fields, see Ky. Agr. Exp. Sta. Buls. 322 and 331.

It seems reasonable to believe that these relations between white clover and bluegrass are largely correlated with the available nitrogen balance in the soil. In the frequently or continuously closely grazed pasture, it appears that the competing grass is removed so rapidly that it is unable to occupy a dominant position over white clover. By this process, also, available nitrogen is rapidly removed from the soil, making conditions less favorable for grass and favoring the dominance of white clover. In continuously undergrazed pastures, however, the available nitrogen supply appears to be removed so slowly that nitrification alone is sufficient to maintain for a few to several years bluegrass in the dominant position. Continually without white clover, however, the available nitrogen content becomes gradually lower, even though the total nitrogen content actually remains constant or even increases. The bluegrass concurrently becomes thinner and less vigorous and soon white clover becomes prominent. This is followed by bluegrass in the dominant position again.

The place that legumes have in the maintenance of bluegrass sod and productivity is shown by some experiments on the Experiment Station farm at Lexington in which all legumes were kept out of bluegrass sods in comparison with other sods in which legumes were maintained at least part of the time.

The first measurement of this effect was obtained from an experiment conducted by Karraker[5] in connection with soil nitrogen studies. In the fall of 1923, Kentucky bluegrass was sown in four plats on the Station farm at Lexington. White clover was also sown on two of the plats. All legumes were kept off the other two plats. In the two plats

[5]KARRAKER, P. E. Note on the increased growth of bluegrass from associated growth of sweet clover. Jour. Amer. Soc. Agron., 17 : 813–14. 1925.

seeded to bluegrass and white clover, sweet clover volunteered abundantly in 1924 and was permitted to make large growth, but was removed in 1925, just before seed matured. While the clipped material usually was left on the plat without weighing, it was harvested once in 1926 and twice in 1928. The total harvest from the three cuttings yielded at the rate of 2,600 pounds of dry matter per acre on the grass-alone plat and 6,100 pounds on the grass-legume plat. Practically all the material was bluegrass. The herbage from the legume-free plat averaged 1.56% of total nitrogen and that from the grass-legume plat 2.17%, an increase of nearly 40%. Perhaps it may be of interest that during the 8 years of this experiment, there was a gain in total nitrogen of 132 pounds per acre for the legume-free plats and 684 pounds for the grass-legume combination. The total nitrogen in the surface 18 inches of soil was not increased appreciably under the legume-free herbage, whereas it was increased 400 pounds under the grass-legume combination. At the end of 10 years the sod on the legume-free plat was light and weedy, while that on the bluegrass-clover plats was heavy and free of weeds.

A series of plats was established in 1927 for the express purpose of ascertaining not only the effect of a legume on bluegrass with which it grows from time to time, but also the relative value of different legumes for association with bluegrass. The legumes were, of course, included in the initial sowing on their respective plats. Since then, however, the legume content of the grass-legume plats has not been comparable, primarily because of differences in life history; consequently, it will be many years before any reliable statement can be made regarding the relative merit of any particular legume for improving bluegrass pastures. But the total dry matter production from the alfalfa, sweet clover, red clover, alsike clover, annual lespedezas, and white clover plats in contrast with that from the no legume-bluegrass plat shows the decided value of legumes in pasture production. The no-legume grass plats from 1929 to 1934, exclusive of the last cutting of 1934, have yielded at the average annual rate of 1,670 pounds of dry matter per acre as hay, and the legume-grass plats at 3,590 pounds, an increase of approximately 115%.

These yields are of all the herbage on the plats and consequently indicate little of the legume effect on the bluegrass alone. While it will be impossible to draw reliable conclusions relative to this effect for many years, the yields from certain plats which were free of legumes in some years are significant. For example, the red clover plat was free of that legume in 1931 and 1932. In those years it produced an average annual yield of 2,774 pounds of dry matter as hay, while the legume-free plat beside it produced 1,867 pounds, a difference of 49% in favor of the red clover plat. Again, the first cutting of hay from the legume-free plat in 1934 yielded at the rate of 259 pounds of dry matter to the acre, while the white clover-bluegrass plat yielded 432 pounds, or an increase of 66%, from the residual effect of white clover.

These yields present a very imperfect picture of the situation, however, because all the material from the legume-grass plat was bluegrass, while a large amount of that from the legume-free plat was

weeds. Moreover, legumes not only increase the yield of pasturage and improve bluegrass sod, but they increase the protein content of the herbage of the grass-legume mixtures in comparison with that of the herbage from the grass-alone plats, as illustrated by a representative analysis. The clipping from the bluegrass-white clover plat on September 22, 1933, which consisted of both plants, contained 19.75% protein, while that from the contiguous legume-free plat contained 14.95% of protein, or an increase of 32% in favor of the herbage containing white clover.

The residual effect of the legume also increases the crude protein content of bluegrass. This may be illustrated by a representative analysis. As has been indicated, the white clover-bluegrass plat contained a vigorous stand of white clover in 1933. It disappeared in June 1934; yet the August 22, 1934, clipping from that plat contained 17.95% protein, whereas the clipping of the same date made from the contiguous legume-free plat contained 13.25% protein, or a difference of 35% in favor of the grass which had a legume with it previously.

Legumes appear to affect associated grass in another particular that may be fully as important in the improvement of pastures for high-producing and fast-growing livestock, namely, in increasing the mineral content of the grass. This statement is based on one chemical analysis of bluegrass growing in association with white clover and one analysis of bluegrass growing just outside the boundary of the white clover-bluegrass areas. These samples were taken at the same time from a bluegrass sod of long standing in which there were areas with bluegrass and white clover growing in association and areas of bluegrass in which no white clover could be found. The herbage was 3½ to 4 inches tall when harvested. The analyses are shown in Table 2.

TABLE 2.—*Chemical composition of white clover and Kentucky bluegrass growing in association and of bluegrass growing alone.**

Association	Total protein %	CaO %	P_2O_5 %	SiO_2 %	K_2O %
White clover growing with bluegrass.....	29.55	2.19	0.98	0.70	4.85
Bluegrass growing with white clover.....	22.03	0.80	1.00	1.62	3.52
Bluegrass growing alone................	16.52	0.68	0.85	2.50	2.96

*Most analyses given in this paper were made by Howell D. Spears, chemist of Feed Control Department, Kentucky Agricultural Experiment Station, as part of a cooperative project between him and the author.

The analyses in Table 2 indicate not only that bluegrass growing in association with white clover contains larger amounts of certain elements necessary in livestock nutrition than does bluegrass growing alone, but also that a white clover-bluegrass association produces forage much richer in those elements than even the bluegrass growing in association with the white clover.

It would be of interest and of value to know how long the bluegrass alone mentioned in Table 2 had been without white clover, because that would give even more information on the immediate effect of the clover. However, the area from which the samples were chosen has

usually had white clover in spots; and since the grass itself was vigorous, it is certain that the grass had the benefit of the legume association within the last few years. It would also be of interest to know what the residual effect of legumes is on increasing the mineral content of bluegrass, but samples taken for this purpose have not yet been analyzed.

Perhaps the most striking effect of a legume on bluegrass is that which is visible to the eye. A statement has previously been made that sods in which a legume is frequently present are practically free of weeds, while that sod which is kept free of legumes becomes thin and weedy. This is only part of the observable difference, however. The differences in number of tillers, recovery after clipping, and color are equally striking. The rate of deterioration of bluegrass sod when legumes are kept out is rather rapid. Under such conditions the grass becomes thin and lighter green, and in from 4 to 8 years becomes weedy.

Summarizing, it may be said that legumes improve pastures by (1) directly and indirectly increasing the total dry matter production, (2) by improving the vigor of the grass sods and preventing weed growth, and (3) by increasing the protein and mineral content of the pasture herbage.

Before concluding, perhaps it should be frankly acknowledged that this paper is not the presentation of a body of data on the place of legumes in pasture production. It is rather an attempt to explain our philosophy of the initial pasture production program—a philosophy based on the foundation of observed differences in the production, management, and ecology of the pastures of the bluegrass region of Kentucky in contrast with those of the rest of the state. In doing this, bits of data from some studies at the Kentucky Agricultural Experiment Station have been presented—studies conducted to obtain a better understanding of the pastures of central Kentucky for the two-fold purpose of learning how to produce good pastures in the rest of the state and how, if possible, to improve the bluegrass pastures of central Kentucky.

The high phosphorus and calcium content of the soil of central Kentucky is believed to be fundamentally responsible for the excellent pastures in that region. The better pastures are on soils ranging in phosphorus from 3,000 to 20,000 pounds and more in 2,000,000 pounds of soil, the average being perhaps 7,000 pounds. The phosphorus is chiefly in the form of tricalcium phosphate, assuring an abundant supply of nutrient calcium as well as of phosphorus. Other minerals, while not so high proportionately are abundant. The total nitrogen content is about 4,000 pounds.

It appears that legumes have been indispensable in the production of the pastures of central Kentucky for reasons presented in this paper, and that the legumes have had that part because of the mineral content and favorable reaction of the soils. This combination has produced famous pastures. Can they be duplicated elsewhere? We know that by the liberal use of limestone and phosphate on most soils of Kentucky, good pastures of grasses and legumes can be produced.

Finally, can highly productive pastures such as those of central Kentucky be improved, especially for more intensive pasturing? That cannot be answered yet, though there is evidence that they can be. Studies pertaining directly to pastures have been in progress only about 10 years, and some of these studies are necessary to a proper perspective. Time is a very important element in pasture studies because nature must be given time to show her reaction to our efforts.

THE RELATIVE SEED YIELDS IN DIFFERENT SPECIES AND VARIETIES OF BENT GRASS[1]

H. F. A. NORTH AND T. E. ODLAND[2]

SINCE the close of the World War the growing of fine bent grass for seed has spread rapidly from Germany to New Zealand, Rhode Island, the Maritime Provinces in Canada, the Pacific Northwest, and to New Jersey. The production of fine bent seed was a thriving industry at an earlier period in Rhode Island as well as in much of New England and New York. Much of the acreage of bent harvested for seed at present is found in naturalized stands. Practically pure stands of colonial and creeping bents are frequently found. Naturalized stands of velvet bent are found infrequently and usually consist of mixtures with other bents. The bents, and especially Rhode Island colonial bent, have been planted in Rhode Island for a number of years in order to produce purer seed and larger yields than are usually obtained from naturalized stands.

Redtop early became naturalized in southern Illinois where a large part of the seed is now produced. Fine bents are frequently the dominant grasses in pastures and reverting meadows in the more humid parts of the northern states. They form most beautiful lawns in this region. Almost all putting greens in this territory are composed largely of bent grasses. The various geographic sections of the United States have been found to favor different bent grasses.

There are many new strains of the bent grasses which have been tested during recent years and a variety of superior kinds are now available for the vegetative planting of putting greens or lawns. Growers of bent seed are faced with many problems as they attempt to grow the new strains for seed. Rhode Island farmers have been able to produce satisfactory yields of colonial bents and fair yields of velvet bent, but have had only indifferent success with creeping bent seed production.

LITERATURE CITED

Burlison and others (1)[3] state that redtop in Illinois is a crop that will maintain a stand for a number of years, depending on the fertility of the soil and the use made of the crop. The duration of the stands varied from 3 to 15 years with an average of 6 years. Lime and phosphorus were found to increase markedly both the yield of seed and of hay. The crop was found to mature seed approximately July 15 and to shatter badly after 10 days or more beyond this date. It is recommended that the crop be harvested for seed not later than one week after blooming is completed. Yields of redtop averaged 54 pounds per acre during the period from 1922 to 1932 and varied from an average of 30 pounds per acre in 1925 to 75 pounds in 1927.

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[3]Figures in parenthesis refer to "Literature Cited," p. 383.

An excellent summary of literature pertaining to the bent grasses has been made by Lewis (5, 6). Odland (9), Edler (2), Schoth (10), and LeLacheur (3) describe the growing of fine bent for seed in various important producing areas. Yields of 30 to 60 pounds of seed per acre are quoted by LeLacheur for Prince Edward Island and New Brunswick. The yield in Oregon according to Schoth varied between 50 and 75 pounds, and a yield of 75 pounds of colonial bent per acre has been reported as an average of two years for New Zealand. This is somewhat higher than the average according to Lewis (6). The work of Levy and Saxby (4) shows that seed is harvested in New Zealand largely by stripping.

EXPERIMENTAL

In 1928, experiments were begun by the Rhode Island Agricultural Experiment Station for the purpose of determining the suitability of a number of bent grasses for seed production. In general, the kinds included were those of which it was thought that there would be a demand for seed if it were available.

A comprehensive selection of bent grass seeds and stolons was obtained and planted in turf plats. Redtop, types of colonial bent, creeping bent (stolons and seed), and strains of velvet bent were included. The results of a 3-year comparison of putting quality of the turf produced by these different strains and varieties have been reported by North and Odland (7). Some of the more promising or important of these bent grasses were planted for testing under seed production.

The seed production test included 12 different grasses, each planted in quadruplicate plats 30¼ feet by 10 feet, or 1/144-acre each. Narrow cultivated paths separated the different plats. The plats were edged each season. Except for watering, weeding, and roguing soon after planting, the plats were kept as near as possible under field conditions such as might exist under commercial growing. Some water was used in order to obtain satisfactory stands when plantings were made in unfavorable seasons.

The plats were rolled in late March or early April. All plats were fertilized uniformly in early spring as shown in Table 1.

TABLE 1.—*Fertilizer and lime applied to bent grass varieties for seed production, 1929 to 1934.*

Fertilizing materials	Nutrients (N, P_2O_5, K_2O) applied in pounds per acre						
	1929	1930	1931	1932	1933	1934	Av.
Sulfate of ammonia (N)	100	90	60	60	60	60	72
Superphosphate (P_2O_5)	75	90	90	90	90	90	87
Muriate of potash (K_2O)	75	75	75	45	45	45	60
Limestone	—	—	—	1,000*	—	—	167

*CaO neutralizing equivalent.

Some of the grasses lodged badly during the season of 1930. In order to reduce lodging the applications of nitrogen were decreased from 90 to 60 pounds per acre in subsequent years. Evidence from an adjoining fertilizer experiment on colonial bent (8) indicated that potash applications were unnecessarily high. Accordingly, the acre application was reduced from 75 to 45 pounds of potash in 1932. Lime was applied to all plats in the spring of 1932.

The soil where the experiment was conducted is a moderately fertile silt loam underlain with gravel. Tests of several plats in the area in late autumn have shown

a range of acidity as follows: 1930, pH 4.34 to 4.53; 1932, pH 4.54 to 4.99; and 1933, pH 4.15 to 4.50. A composite sample of the area tested pH 4.45 in November 1934. Obviously, the soil was highly acid during much of the period.

Notes were taken each year on stand, heading, mixture, weeds, and ripening. The grasses were cut with a scythe, cured partially in the swath, shocked, and covered with canvas hay caps. After a thorough curing, the crop was packed into wool bags for storage until air dry and until a time convenient for threshing. Threshing was delayed usually until October or November. The seed was flailed out in 1930, while in the following years a small thresher was used. In order to remove a larger part of the straw a special straw rack was constructed for the thresher which had finer perforations than that used for cereals. No air blast was used during threshing.

Considerable time was consumed in working out the technic of cleaning the seed. Special screens and careful regulation of the air blast were found highly important. Actual yields per plat in grams of cleaned seed were calculated to pounds per acre. The weight per bushel of the seed obtained was determined during the period from 1930 to 1933.

RESULTS

The appearance and growth habit varied widely between the bents. In Table 2 will be found data on the stand in early spring and the height, date, and amount of lodging when ripe. For the most part the figures represent an average of 20 estimates and should be fairly accurate. The percentage scores for putting quality cover four seasons.

Stands of 90 to 100% are considered good, those in the 80's fair, and below 80 poor. Satisfactory stands have persisted in redtop, the colonials, and in some strains of velvet bent. Stands of creeping bent either died out, became weedy, or became mixed with colonial and velvet bents. Seaside creeping bents tended to show larger amounts of bent mixture than the stolons. Some of these plats were dug up in 1931 because they were heavily mixed with colonial bent. Redtop, colonial, and the velvet bents were relatively free from weeds and mixture depending somewhat upon the stand.

Redtop was found to grow to approximately three times the height of Washington creeping bent. Metropolitan and Virginia were short also, while the seaside creeping bent grew approximately as tall as the colonial bents. Among the velvet bents, No. 14,276 was tall, Highland intermediate, and Kernwood rather short.

The colonials and redtop have ripened earlier in general than the creeping bents and the latter somewhat earlier than the velvet bents. Almost as much difference in time of ripening was found between strains within a species in creeping and in velvet bent as was found between two species such as colonial bent and creeping bent. The dates of ripening recorded in 1930 and 1931 were considerably later than those during 1932 and 1933. It is this difference which accounts for the apparent lateness of two of the samples of seaside creeping bent tested as compared with the third. Many of the grasses lodged during 1930 and 1931, probably as a result of the high applications of nitrogen at that time. Lodging was found to be progressively heavier in the species as follows: Creeping bent, colonial bent, redtop, and velvet bent.

The scores for the same grasses in putting green turf varied from 44% for Virginia creeping to 88% for No. 14,276 velvet bent. The velvet and colonial bents scored higher than did the creeping bents. The ratings for quality of turf have been much the same for the seed and vegetative plantings of those strains of creeping and velvet bent in which both plantings have been made. The quality of turf from the plat-grown seed compared favorably also with the quality of the turf from original seed in colonial and seaside creeping bents.

TABLE 2.—*Data on the growth of different bent grasses grown for seed, average, 1930 to 1934.**

Species and type or strain	Stand %	Height in inches	Date ripe	Lodging %	Lodging Degree	Score of turf, 1931–34, %
Redtop (*A. alba*)	97	32	July 27	21	32	*45*
Colonial (*A. tenuis*):						
Type a, Rhode Island	100	21	July 28	15	17	79
Type b, Astoria	98	21	July 26	24	27	79
Type c, Oregon bent†	*99*	*20*	*July 21*	*0*	*0*	79
Creeping (*A. palustris*):						
Metropolitan stolons	96	13	July 30	6	11	71
Virginia stolons	68	13	Aug. 4	12	11	44
Washington stolons	78	11	Aug. 3	4	1	66
Seaside:						
Coos Co., Ore., seed	*96*	*24*	*Aug. 7*	*9*	*14*	69
Marshfield, Ore., seed	*98*	*25*	*Aug. 7*	*4*	*4*	60
Oregon, seed	*98*	*19*	*July 24*	*1*	*4*	67
Velvet (*A. canina*):						
Highland stolons	83	17	Aug. 4	27	18	80
Kernwood stolons	96	16	Aug. 7	35	26	86
B. P. I. 14,276 stolons	91	23	Aug. 6	43	49	88
Yorkshire stolons	68	18	Aug. 6	34	42	72

*Figures in italics are for 2-year averages only.
†Name in Oregon. In New Zealand it is called dryland browntop.

In Table 3 will be found the yields of cleaned seed each season and the average yield for the period of 1930 to 1934.

Redtop yielded more than any of the fine bents each year except the last and averaged 217 pounds of seed per acre. This is nearly four times the average yield reported for the area in Illinois where it is produced commercially.

The yields of Rhode Island colonial varied from 47 to 264 pounds per acre and averaged 114 pounds. It was out-yielded by Astoria colonial bent. Oregon bent formed a more open growth and yielded significantly less seed than the representatives of types a and b colonial, although it remained relatively pure.

Among the strains of creeping bent, Metropolitan and Virginia were found about equal and both higher in seed-yielding ability than Washington creeping bent. Stands of Washington creeping bent have been somewhat less permanent than stands of the other two strains, although all of the strains became mixed or died out after two or

TABLE 3.—*Yields of recleaned seed of different bent grasses during the period of 1930 to 1934.*

Species and type or strain	Method of planting	Cleaned seed, pounds per acre					
		1930	1931	1932	1933	1934	Average
Redtop (*A. alba*)	Seed	356±35	157±19	293±30	160±16	117±10	217±11
Colonial (*A. tenuis*):							
Type a, Rhode Island	Seed	264±26	82±10	104±11	47± 5	73± 6	114±6
Type b, Astoria	Seed	310±31	97±12	110±12	76± 7	94± 8	137±7
Type c, Oregon bent	Seed	—	—	—	100±10	23± 2	62±5
Creeping (*A. palustris*):							
Metropolitan	Stolons	—*	—†	231±24	68± 6	63± 5	121±8
Virginia	Stolons	275±27	39± 5	26± 3	—*	—*	113±9
Washington	Stolons	153±15	12± 1	—*†	75± 7	47± 4	72±4
Seaside:							
Coos Co., Ore.	Seed	178±17	80±10	—‡	—	—	129±8
Marshfield, Ore.	Seed	122±12	88±11	—‡	—	—	105±8
Oregon	Seed	—	—	—	60± 6	67± 6	63±4
Velvet (*A. canina*):							
Highland	Stolons	152±15	127±15	158±17	77± 7	141±12	131±6
Kernwood	Stolons	129±13	26± 3	118±12	58± 6	63± 5	79±4
B. P. I. 14,276	Stolons	34± 3	26± 3	85± 9	57± 6	86± 7	58±3
Yorkshire	Stolons	—	10± 1	24± 2	—*	—*	17±1

*Crop failure.
†Replanted.
‡Replanted; changed to new variety; badly mixed.

three seed crops. It was unfortunate that such a great amount of mixture with colonial bent occurred in the seaside creeping bents since on this account the yields are not representative. The average yields for 2 years indicate that seaside creeping bents yielded considerably less than the colonial bents.

The average yield among the velvet bents ranged from 17 pounds per acre for Yorkshire to 131 pounds for Highland. The consistently high yields of Highland are responsible for its rank slightly higher than Rhode Island colonial. The yields of the other velvet bents were very low in 1931 and as an average of the five crops were considerably below the colonials. Yorkshire yielded very poorly and did not persist well in seed production.

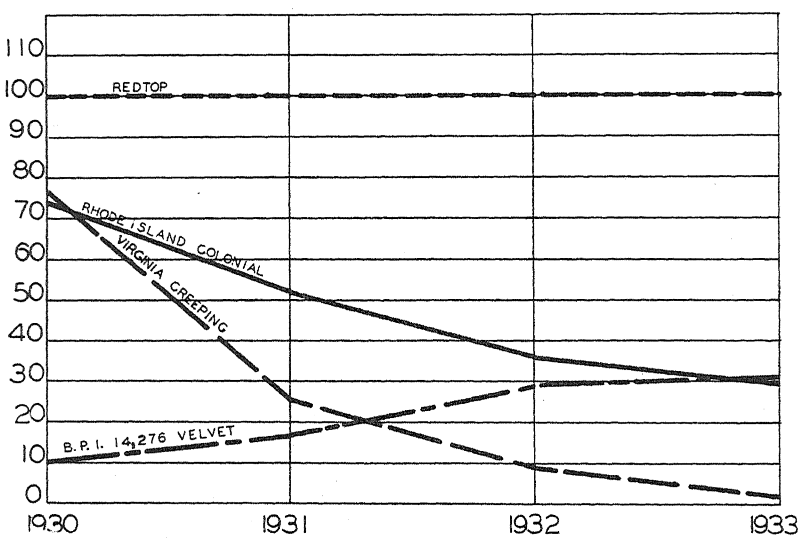

FIG. 1.—Bent seed yields in per cent with redtop held constant each year.

Fig. 1 shows the trend in yields of typical grasses of each species during the test. Taking the yield of redtop as 100% each year, it is evident that the percentage yield of colonial bent has been gradually falling off. The yield of creeping bent, although relatively high at the beginning, failed completely by the end of the fourth crop year. The velvet bents have shown a more or less pronounced trend upwards in relation to redtop. Velvet bent B. P. I. No. 14,276, has shown gradual improvement and finally produced a larger yield than Rhode Island bent by the end of the period.

It has been shown in this and other experiments that creeping bents are much more sensitive to acid soil conditions than are colonial and velvet bents. Velvet bents have been found more tolerant of such soil conditions than the colonial bents. These facts may explain in a large measure the difference between the trends in yield.

QUALITY OF SEED

An effort was made to clean the seed from each plat uniformly and to obtain a marketable product. As a check on the quality, the weight per bushel of the cleaned seed of each variety was determined each year. Germination and purity tests were made in the local laboratory and also on a few samples by submitting them to the Rhode Island State Department of Agriculture for official test.[4] The velvet bents were cleaned on the same machine each season, while other varieties were cleaned on a larger machine of the same type. The operators were the same during the period of 1931 to 1934. Data on weight per bushel for the different varieties are shown in Table 4. The figure for each season represents the average of quadruplicate plats.

TABLE 4.—*Weight per bushel of recleaned seed of different bent grasses grown during the period of 1930 to 1934.*

Species and type or strain	Pounds per bushel					
	1930	1931	1932	1933	1934	Average
Redtop (*A. alba*)	25.9	21.2	27.1	26.3	21.7	24.4
Colonial (*A. tenuis*):						
Type a, Rhode Island	28.6	20.9	30.6	27.0	20.5	25.5
Type b, Astoria	25.6	21.9	28.7	29.1	25.7	26.2
Type c, Oregon Bent	—	—	—	27.1	20.2	23.6
Creeping (*A. palustris*):						
Metropolitan stolons	—	—	26.6	26.5	22.5	25.2
Virginia stolons	21.2	22.0	30.7	—*	—	24.6
Washington stolons	20.6	24.1	—	28.2	25.0	24.5
Seaside:						
Coos Co., Ore., seed	27.2	22.4	—	—	—	24.8
Marshfield, Ore., seed	24.8	20.3	—	—	—	22.5
Oregon, seed	—	—	—	28.4	22.2	25.3
Velvet (*A. canina*):						
Highland stolons	19.2	19.4	25.4	22.4	22.5	21.8
Kernwood stolons	21.9	22.6	29.3	22.9	23.2	24.0
B. P. I. 14,276 stolons	20.8	19.6	24.4	29.5	26.1	24.1
Yorkshire stolons	—	14.4	21.4	—	—	17.9

*Insufficient volume for determination.

In general, a high weight per bushel is correlated with a high proportion of seed in relation to yield of hay. Hay yields have remained more constant than seed yields. The latter varied considerably from year to year. The average weights per bushel for the period tend to be lower for the velvet bent seed than for that of the other kinds. This may be due in part to a necessary reduction in the air blast used in cleaning the velvet bent seed. The velvet bent seeds are very small and only a light air blast can be used. The seed of Kernwood and of

[4]Credit is due F. A. McLaughlin, Massachusetts State Seed Analyst, for making the tests of samples submitted through the Rhode Island State Department of Agriculture. The authors are also indebted to M. H. Brightman of the Rhode Island Department of Agriculture for arranging for these tests to be made.

No. 14,276 were heavier each year than that of Highland velvet bent. Yorkshire was very low, both in weight per bushel and in yield. Redtop, colonial bents and creeping bents had approximately the same average weight per bushel.

There are a number of factors which tend to reduce the weight per bushel of the seed, although the speed, screens, and air blast are held constant in the cleaning process. Some of the more important factors are as follows: Immature seed, large perforations in the thresher screens, hasty cleaning, and retaining double-hulled seeds. Smutted seeds have not reduced weight per bushel to any great extent thus far. The weight per bushel has varied from 14 to 30 pounds per bushel and has averaged approximately 25 pounds. The highest quality of bent seed on the market will weigh 30 pounds per bushel or over.

Table 5 shows a comparison of analyses and weight per bushel of the samples submitted for official test.

TABLE 5.—*Purity and germination tests of seed of certain bents during the period of 1931 to 1933.*

Year	Plat	Purity %	Weeds %	Inert %	Other crop seeds %	Germination %	Weight per bushel, lbs.	Remarks
				Kernwood Velvet Bent				
1931	B-46	63.0	Trace	37.0	None	83	25.5	
1932	B-46	96.5	0.01	2.9	0.5	92	29.7	
1933	B-46	79.8	0.02	18.9	1.2	68	19.5	Much smut
				Rhode Island Colonial Bent				
1931	B-6	91.8	Trace	8.1	None	88	21.3	
1932	B-6W	98.9	0.02	1.0	Trace	94	30.2	
1933	B-6W	94.2	0.03	3.9	1.8	60	27.5	Much smut
				Virginia Creeping Bent				
1931	B-3	80.0	Trace	19.0	1.0	87	19.4	
				Washington Creeping Bent				
1933	B-1W	86.4	7.0	4.7	2.8	87	31.0	No disease
				Metropolitan Creeping Bent				
1932	B-45	75.0	0.07	1.9	23.0	93	26.0	
1933	B-45	70.9	0.02	6.5	22.6	82	26.0	Few smutted

Comparisons of purity and weight per bushel indicate that considering the sum of pure seed and other crop seeds in the sample that bent seed weighing about 30 pounds per bushel will test approximately 98% pure. In a similar way, seed weighing 20 pounds will test approximately 80% pure. A more complete set of analyses are needed in order to approximate the purity of samples between these extremes in weight per bushel.

The tests show that weed seeds had been largely removed during cleaning. The percentage of inert material varied considerably and tended to be low in 1932, a year when the seed yield was high, and high in 1931 when the yield was low. "Other crop seed" consisted

entirely of bent seed of other kinds. The velvet and colonial bents had small amounts in the fourth seed crop, while creeping bents showed a much larger amount by that time.

The percentage of germination was satisfactory except for the velvet and colonial bent samples of 1933. The low germination of this was largely due to smut. It is notable that creeping bent seed was relatively free from smut and germinated reasonably well.

SUMMARY AND CONCLUSIONS

The fine bent grasses have been found eminently adapted for putting greens over much of the northern half of the United States. Fine bents have formed beautiful and enduring lawn turf in New England since colonial times, and more recently have been found valuable in a variety of sports turf.

The growing of these grasses for seed has become an important industry in certain sections of this country. Very little investigational work on the problems of bent seed production has been reported. Results of experimental work at the Rhode Island Agricultural Experiment Station on seed production of different species and varieties of bent grass are reported in this paper.

Experiments were begun for the purpose of obtaining an estimate of the yield of seed that might be expected under commercial production and at the same time to discover how closely the seeded turf would resemble the turf from a vegetative planting in a number of strains. Other experiments that have been reported in previous publications concerned fertilizer tests on colonial bent grown for seed and the relative value of the different bents for golf greens.

It has been shown that the turf from seed and the turf from vegetative planting in a strain tend to become very similar in putting quality.

Quadruplicate plats were planted with 12 different bent grasses and satisfactory stands were secured. The species included were *Agrostis alba*, *A. tenuis*, *A. palustris*, and *A. canina*. Rather high levels of fertility were maintained. Tabular data on the growth and yield of recleaned seed are presented for the years 1930 to 1934.

Colonial and velvet bents were found to continue relatively free from weeds and mixtures in practically full stands. Although mixing with colonial bent was evident in plats of redtop before lime was applied, the stands continued relatively pure.

Stands of creeping bent were short lived and permitted of invasion by weeds and other bent grasses.

The yield of seed varied widely from year to year and varied also among the grasses. The average yield of seed for the period varied from 58 pounds per acre for B. P. I. 14,276 velvet bent to 213 pounds for redtop. Astoria colonial out-yielded Rhode Island colonial by about 20%. Highland velvet bent yielded about 15% more than Rhode Island colonial.

Based upon the seed yield of redtop, there was a gradual downward trend in the percentage yield of the colonials, a gradual upward trend in velvet bents, and a rapid downward trend in creeping bents.

The experiments indicate that the improved vegetative strains of velvet bent can be successfully grown for seed production, but that the stolon strains of creeping bent are more difficult to grow for this purpose.

The high quality of velvet bent turf for the putting green and lawn may be expected to increase the demand for the seed. Seed of exceptional strains, such as B. P. I. 14,276 and Kernwood, should command a special premium in price.

LITERATURE CITED

1. Burlison, W. L., Stewart, C. L., Ross, R. C., and Whalin, O. L. Production and marketing of redtop. Ill. Agr. Exp. Sta. Bul. 404. 1934.
2. Edler, G. C. Bent seed production in Germany. Bul. U. S. Golf Assoc., Green Sec., 10 : 205. 1930.
3. LeLacheur, G. Canadian certified bent seed. Bul. U. S. Golf Assoc., Green Sec., 10 : 212–213. 1930.
4. Levy, E. Bruce, and Saxby, Stephen H. Strain investigation of grasses and clovers (Cont.) : 5. Browntop (*Agrostis tenuis*). N. Z. Jour. Agr., 43 : 1–10. 1931.
5. Lewis, I. G. A greenkeeper's guide to the grasses, 3.—The genus *agrostis*. Jour. Bd. Greenkeeping Res., 3 : 148–152. 1934.
6. ————. A greenkeeper's guide to the grasses, 3.—The genus *agrostis* (cont.) : Browntop (*Agrostis tenuis*, Sibth). Jour. Bd. Greenkeeping Res., 3 : 200–206. 1934.
7. North, H. F. A., and Odland, T. E. Putting green grasses and their management. R. I. Agr. Exp. Sta. Bul. 245. 1934.
8. ————, ————. Seed yields of Rhode Island colonial bent (*Agrostis tenuis* Sibth) as influenced by the kind of fertilizer applied. Jour. Amer. Soc. Agron., 26 : 939–945. 1934.
9. Odland, T. E. Bent grass seed production in Rhode Island. Bul. U. S. Golf Assoc., Green Sec., 10 : 201–204. 1930.
10. Schoth, H. A. Bent grass seed production in the Pacific Northwest. Bul. U. S. Golf Assoc., Green Sec., 10 : 206–211. 1930.

AN ANALYSIS OF SOIL AND SEASONAL EFFECTS IN ALFALFA VARIETY TESTS[1]

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DURING recent years considerable interest has been attached to field experimental technic as evidenced by the 1933 report and bibliography of the committee of the American Society of Agronomy on standards for the conduct and interpretation of field and lysimeter experiments. An opportunity has been given the writer to analyze certain phases of alfalfa varietal testing, and, alfalfa being a perennial crop, the results may indicate certain problems which are not apparent in the testing of annual crops.

Two problems have been investigated in the present paper concerned with alfalfa testing, *viz.*, the number of years required to determine relative yields for a given set of plats, involving the question of differential response to season; and the relative importance of "place effect" in field trials of this crop. The term "place effect" is not used in the sense of regional effect, but rather in the sense of field heterogeneity on the same farm. Although variety tests from four different states are used, no attempt has been made to study the varieties, as such, in different regions of the country. The different stations were chosen chiefly to determine if conclusions from tests in one region of the country would or would not substantiate those from other regions.

METHODS

Through the courtesy of the various cooperating institutions, detailed data of the yields of replicated plats of alfalfa varieties were obtained for this anlaysis. Since the yield of the varieties, as such, are not concerned, the detailed data are not given, but information is presented in Table 1 to give an adequate understanding of the amount of data upon which the calculations are based.

The relative stand of plants is no doubt a factor in the present study, but an analysis of its relation to production is impossible with the data at hand. Care was taken to omit those varieties from consideration where the stand was obviously too thin for maximum production since those varieties which thin out rapidly demonstrate their undesirability and yield data are unnecessary. In all tests analyzed systematic replication was the rule, and objections may be raised to using certain statistical methods on systematic distributions. It is believed,

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[2]Associate Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. It is a pleasure to acknowledge the courtesy and cooperation of the men in charge of alfalfa investigations at the experiment stations at Holgate, Ohio; Manhattan, Kans.; Lincoln, Nebr.; and Redfield, S. D.; cooperating with the Division of Forage Crops and Diseases, and to H. L. Westover and E. A. Hollowell of the latter division through whom it was possible to obtain the data necessary for the analysis. The author is also indebted to F. R. Immer for criticism of the manuscript.

however, that the methods herein applied probably can be as readily justified as other methods of statistical procedure.

Two methods of analysis are used, the zero order correlation coefficient and Fisher's analysis of variance. The correlation coefficient is used to measure the relative consistency of 1 or 2 year's yields compared to the final yield as determined over a period of years. It is also used to measure the relative importance of seasonal and place effect. The analysis of variance is used chiefly to determine the relative importance of seasonal and place effects. In addition a paired comparison is used in comparing check plats in the same test over a period of years to show place effect differences.

Throughout the paper the terms "relative yield" or "relative rank" are used. Particular attention is drawn to these terms because, although the actual yields of varieties may vary greatly from year to year, it is the relative yield from year to year which is here being considered. The relative rank, after all, determines the correct evaluation of varieties.

TABLE 1.—*Description of fields and tests from which data were obtained.*

Location	Field No.	No. of varieties	No. of replications*	Date planted	No. of years tested	Remarks
Redfield, S. D.	—	39	2	Various	4	Upland
Lincoln, Nebr.	1–3	68	3	Various	5	Upland
Lincoln, Nebr.	5	35	2	1930	3	Upland
Manhattan, Kans.	A	38	2	1930	3	Upland
Manhattan, Kans.	F	38	2	1930	3	Bottomland
Holgate, Ohio	A	37	3	1929	3	Level land
Holgate, Ohio	B	37	3	1930	3	Level land

*All tests were laid out in systematic distribution, with check plats of a standard variety every 3rd, 4th, 5th, or 6th plat.

RESULTS

CORRELATION OF 1 OR 2 YEAR'S YIELD WITH SEVERAL YEARS' YIELDS

The mean varietal yields for each year were correlated with the mean yield for the total number of years the varieties were under test. The yields were also grouped as, for example, the first 2 years or the last 2 years, and correlated with the final yield. The results for seven different fields, representing 292 lots and 2,220 individual annual plat yields, are given in Table 2.

In general, all correlation coefficients are high, but the first and last years are less consistent than the second year. Lack of being well established may account for the low correlations the first year. At the Redfield, S. D., station there is a negative correlation between the first year's yields and the 4-year average. This is probably due to combining different fields and different planting dates with resulting variations in yielding ability for a given year. When all yields at Redfield were computed to a relative basis a positive correlation coefficient of .653 resulted instead of the negative correlation of —.385. Since all other correlations are based on actual yields, the negative correlation is left in Table 2. Considering only the second year, all fields have a .9 correlation or higher when compared with the average

yield of 3 or 4 years. When the first 2 years or the second and third years are combined and correlated with the final averages, all coefficients are high, there being only 2 out of the 14 which are lower than .93. When it is considered that there is variability and error connected with the determination of each individual yield, these correlation coefficients are very significant and, as will be noted in the discussion, lead to the conclusion that probably 2 years' yield determinations are sufficient for ranking varieties for yielding ability. It may be noted that Redfield, S. D., having the lowest precipitation, has the lowest correlations, while Holgate, Ohio, having the highest precipitation, has the most consistent and highest correlations.

TABLE 2.—*Summary of correlation coefficients showing the relation between 1 or 2 year's production and the average production over a period of years.*

Mean yield for all years correlated with yield of	Redfield, S. D.	Lincoln, Nebr.		Manhattan, Kans.		Holgate, Ohio	
		1–3	5	A	F	A	B
1st year....	—.385	.850	.739	.793	.942	.929	.953
2nd year....	.927	.940	.904	.922	.953	.971	.974
3rd year....	.651	.927	.659	.895	.466	.976	.948
First 2 years	.713	.979	.959	.976	.976	.992	.986
2nd and 3rd years.....	.947	.964	.892	.934	.952	.995	.980

Certain objections may be raised to correlating 1 or 2 year's results with the average of 3 years, when the latter is partly made up from the first two. This procedure is felt to be justified in that the final ranking of the varieties in an ordinary test is based on the 3 or 4 years' yield (as the case may be) and our present object is to determine how divergent are the results from 1 or 2 year's test. This can be determined only by comparing the result of 2 years' yield with the final yield as determined over a longer period of years.

Naturally, it is also of interest to obtain correlations, for example, of the first year with the second and of the second with the third. This has been done for two locations and the results tabulated in connection with the comparison of seasonal and place effects in the first part of Table 4. Even when individual years are correlated the correlations remain high in four out of six cases. The low correlation on field F at Manhattan between the years 1932 and 1933 can be largely explained by the fact that bacterial wilt had decidedly thinned some of the stands by 1933, resulting in a decreased yield for these plats. The correlation of field A, Manhattan, for 1931 and 1932 is possibly low because the alfalfa had not become fully established on the upland.

COMPARISON OF SEASONAL AND PLACE EFFECTS

An analysis of variance was made for the data from three different stations to determine if the variability due to years was greater or less than that due to replications. In order to present more clearly

the various steps involved in arriving at the variance table, Example 1 is given showing the detailed calculations for a hypothetical setup involving three varieties each having three replicates and tested for 4 years. The example shows the manner of obtaining the variance of the interaction of varieties and years and that of varieties and replicates, which are of most interest in the present analysis.

EXAMPLE 1.—*Calculation of variance using three varieties with three replications and tested for 4 years.*

Year	Yield of varieties A, B, and C, by plats															Tota by years
	Variety A			Total by var.	Variety B			Total by var.	Variety C			Total by var.	Total by replicates			
	Replicate				Replicate				Replicate							
	1	2	3		1	2	3		1	2	3		1	2	3	
1929	4.2	3.5	3.7	11.4	4.8	4.2	3.8	12.8	3.4	3.8	3.9	11.1	12.4	11.5	11.4	35.3
1930	3.6	3.2	3.5	10.3	4.3	4.0	3.9	12.2	3.0	3.2	3.2	9.4	10.9	10.4	10.6	31.9
1931	4.5	3.8	3.9	12.2	5.0	4.8	4.2	14.0	3.8	4.0	4.1	11.9	13.3	12.6	12.2	38.1
1932	4.0	3.6	4.0	11.6	4.6	4.5	4.0	13.1	3.6	3.0	3.7	10.3	12.2	11.1	11.7	35.0
Totals	16.3	14.1	15.1	45.5	18.7	17.5	15.9	52.1	13.8	14.0	14.9	42.7	48.8	45.6	45.9	140.3

Mean = 3.89722

Calculation of Sums of Squares*

$$\text{Between varieties} = \frac{45.5^2 + 52.1^2 + 42.7^2}{12} - (140.3 \times 3.89722) = 3.88$$

$$\text{Between years} = \frac{35.3^2 + 31.9^2 + 38.1^2 + 35.0^2}{9} - (140.3 \times 3.89722) = 2.14$$

$$\text{Between replicates} = \frac{48.8^2 + 45.6^2 + 45.9^2}{12} - (140.3 \times 3.89722) = .52$$

Total between varieties and years =

$$\frac{11.4^2 + 10.3^2 + 12.2^2 + 11.6^2 + 12.8^2 \text{ etc.}}{3} - (140.3 \times 3.89722) = 6.22$$

Interaction of varieties and years = difference = $6.22 - (3.88 + 2.14) = .20$

Total between varieties and replicates =

$$\frac{16.3^2 + 14.1^2 + 15.1^2 + 18.7^2 \text{ etc.}}{4} - (140.3 \times 3.89722) = 5.65$$

Interaction of varieties and replicates = difference = $5.65 - (3.88 + .52) = 1.25$

Total between years and replicates =

$$\frac{12.4^2 + 11.5^2 + 11.4^2 + 10.9^2 \text{ etc.}}{3} - (140.3 \times 3.89722) = 2.80$$

Interaction of years and replicates = difference = $2.80 - (2.14 + .52) = .14$

$$\text{Total} = \frac{4.2^2 + 3.5^2 + 3.7^2 + 3.6^2 \text{ etc.}}{1} - (140.3 \times 3.89722) = 8.61$$

Remainder = difference = $8.61 - (3.88 + 2.14 + .52 + .20 + 1.25 + .14) = .48$

EXAMPLE No. 1.—*Continued.*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Between varieties	2	3.88	1.940
Between years	3	2.14	.713
Between replicates	2	.52	.260
Interaction of varieties and years	6	.20	.033
Interaction of varieties and replicates	4	1.25	.313
Interaction of years and replicates	6	.14	.023
Remainder†	12	.48	.040
Total	35	8.61	

*The various sums of squares are obtained by squaring the total yield of each of the varieties, years, or replicates, summating, dividing by the number of unit plats contributing to each total, and subtracting the product of the total of all plats times the average of all plats.

†The generalized error of the experiment is obtained from the interaction of varieties and replicates. The standard error of a single plat for a single year in this example would be $\sqrt{.313} = .559$.

Variance for the three locations is found in Table 3. Without exception, the variance due to interaction of varieties and replicates is larger than that due to interaction of varieties and years, and in two cases, significantly larger as determined from the table of significance presented by Snedecor.[3] To examine more carefully into what this means, it needs only to be pointed out that if there was perfect correlation of relative yields between varieties in each of the replicates there would be no "interaction", but if variety A, for example, yields high in replicate 1 and low in replicate 2 while variety B yields low in replicate 1 and high in replicate 2, presumably largely due to soil heterogeneity, the interaction of varieties and replicates would be very great. Similarly, with interaction of varieties and years, if the varieties have the same relative rank one year with the next, there would be very little or no interaction. Thus, the fact that the interaction due to replication is greater than that due to years suggests that improvement in alfalfa varietal testing should first come in the matter of correcting for variations due to soil and related errors.

In replicated varietal tests at Manhattan, Kans., and Holgate, Ohio, the same varieties were planted on two different areas of land, in Kansas the same year and at Holgate in successive years. This arrangement makes it possible to compare the yield of the same varieties the same year on two different fields and the yield of the same varieties on the same field for different years. Altogether there were six such comparisons of year with year and five of field with field, the correlation coefficients of which were averaged by Fisher's method.[4]

The results, given in Table 4, show that the average correlation of yields from the same plats in different years is .7563, while that of results from different fields in the same year is .6194. By Fisher's z test these correlations are significantly different. In these comparisons the means of the replicates were used, not the individual plats. If the

[3]SNEDECOR, GEORGE W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa : Collegiate Press, Inc. 1934.

[4]FISHER, R. A. Statistical Methods for Research Workers. Edinburgh : Oliver and Boyd. Ed. 4. 1932.

individual plats are taken, the difference between the correlations is much greater. Field F in Kansas with two replications, for example, has a correlation of .8265 between years, whereas it is only .5804 between individual plats planted to the same variety. On the other hand, with a larger number of replications there would probably be less difference. The fact that there is higher correlation between

TABLE 3.—*Variance analysis of alfalfa variety tests at Lincoln, Holgate, and Manhattan.*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Field 3, Lincoln, 30 Varieties, 3 Replications, 5 Years			
Between varieties	29	7.40	.255
Between years	4	507.51	126.880
Between replicates	2	1.44	.720
Interaction of varieties and years	116	16.25	.140
Interaction of varieties and replicates	58	8.31	.143
Interaction of years and replicates	8	5.17	.646
Remainder	232	29.04	.125
Total	449	575.12	
Range A, Holgate, 37 Varieties, 3 Replications, 3 Years			
Between varieties	36	32.98	.916
Between years	2	310.82	155.410
Between replicates	2	.70	.350
Interaction of varieties and years	72	5.79	.080
Interaction of varieties and replicates	72	8.33	.116
Interaction of years and replicates	4	1.63	.408
Remainder	144	23.11	.160
Total	332	383.36	
Field F, Manhattan, 38 Varieties, 2 Replications, 3 Years			
Between varieties	37	32.50	.878
Between years	2	111.86	55.930
Between replicates	1	1.53	1.530
Interaction of varieties and years	74	16.16	.218
Interaction of varieties and replicates	37	14.36	.388
Interaction of years and replicates	2	.67	.335
Remainder	74	4.96	.067
Total	227	182.04	

the relative yield of varieties from year to year than from field to field in the ordinary test having one, two, or three replications emphasizes the fact that there may be greater variability due to place effect than to seasonal differences in the testing of a perennial crop where varieties are on the same plats of ground year after year. These results also corroborate those found by analysis of variance.

The place effect also can be analyzed on the basis of check plats which were used in all tests reported. Checks chosen in each replicate falling beside a given variety and compared to another set of checks similarly chosen in another portion of the field of the same test were found to differ significantly in yield over a period of years by Student's odds. An additional test between the checks is obtained by using the

error found by the variance method (the interaction of varieties and replicates) to compare the yields of replicated check plats. In all tests for which variance was obtained it was possible to find replicated plats of the check differing significantly in yield.

TABLE 4.—*Correlation analysis of varieties on the same plats in different years and for the same years in different fields.*

Location	Field	Year	No. paired varieties	No. rep.	r	z	(n-3)	(n-3)z
Correlating Yields on the Same Plats in Different Years								
Holgate....	A	'31 with '32	11	3	.8688	1.328	8	10.624
Holgate....	B	'31 with '32	11	3	.9213	1.598	8	12.784
Manhattan.	A	'31 with '32	38	2	.5342	.596	35	20.860
Manhattan.	F	'31 with '32	38	2	.8817	1.383	35	48.405
Manhattan.	A	'32 with '33	38	2	.8947	1.445	35	50.575
Manhattan.	F	'32 with '33	38	2	.2988	.308	35	10.780
Combined correlation........................					.7563	.9874	156	154.028
Correlating Yields from Different Fields in the Same Year								
Holgate....	A with B	1931	11	3	.6862	.841	8	6.728
Holgate....	A with B	1932	11	3	.6168	.720	8	5.760
Manhattan.	A with F	1931	38	2	.5998	.693	35	24.255
Manhattan.	A with F	1932	38	2	.8011	1.102	35	38.570
Manhattan.	A with F	1933	38	2	.3371	.351	35	12.285
Combined correlation........................					.6194	.724	121	87.598

	r	z	(n-3)	Reciprocal
Years with years.......	.7563	.987	156	.0064
Fields with fields.......	.6194	.724	121	.0083
		.263±.121		.0147

DISCUSSION

The available data for the conditions studied indicate that 2 years' yield from alfalfa in its prime may give practically as reliable results with respect to yielding ability as a 3-, 4-, or 5-year average. This does not mean that the variety test should be confined to a 2 years' yield test, but it is suggested that yields can be taken for perhaps 2 years and observations regarding stand, diseases, etc., can be made over longer periods, possibly supported by controlled tests for such characters as cold resistance and reaction to certain diseases. This system of testing would involve the principle of segregating and interpreting the various factors or characters, such as yield, disease resistance, etc., which together go to make a good variety. Of what value are yields from varieties having only half a stand compared to others having a full stand? In determining the years to be used for the yield test care should be taken to see that the plants are fully established, and, on the other hand, undue thinning of the plats should not have occurred.

The results showing that with few replications (two or three) the variability due to soil is greater than that due to season, emphasizes that certain changes in field technic are desirable. It is probable that sufficient replication and proper distribution, the latter perhaps involving some form of a modified random distribution, would make for a distinct improvement. More frequent plantings would no doubt serve the same purpose as increasing the number of replications with few plantings. With the data at hand it has been impossible to consider such factors as number of replications or size and shape of plats. Such factors will no doubt have to be adapted to the conditions of each test in accordance with the best principles of plat technic. Check plat correction, for example, is sometimes used, but it is improbable that great improvement in accuracy of results can be obtained by including a large number of checks and retaining only one or two replications of the unknown varieties.

Observations of various investigators will enable them to determine for their own conditions if the suggested 2-year period is sufficient to obtain satisfactory varietal yields. If this proves to be the case more emphasis can be given to sufficient replication and proper distribution, so that with approximately the same expenditure better results can be obtained. A further advantage is the possibility of securing reliable yield data from outlying field plats where long-continued yield tests are now impractical. The data clearly indicate that long-continued tests from the same plats do not serve to compensate for errors due to soil heterogeneity, rather, these differences, amounting to errors, tend to accumulate from year to year and lend a false security to the results.

SUMMARY

The number of years of testing required to obtain a reliable index of yielding ability and the relative importance of place effect was studied in alfalfa variety trials conducted at the experiment stations at Redfield, S. D.; Manhattan, Kans.; Holgate, Ohio; and Lincoln, Nebr.

Correlation coefficients between 1 or 2 year's yield and the final yield were very high and judging from the data available for this study 2 years' yield results were practically as indicative of yielding ability as 3, 4, or 5 years' results.

Analysis of variance of alfalfa variety tests indicated greater variability due to place effect than to seasonal effect.

Variance and paired comparison analysis showed that significant differences between replicates of the same variety (the check) could be found in all tests. A higher correlation was found between yields of varieties one year with the next from the same plats than between two different fields for the same year planted to the same varieties, emphasizing the importance of field heterogeneity and that long-continued tests from the same plats do not serve to compensate for these errors.

THE EFFECT OF SOIL CONDITIONS AND TREATMENT ON YIELDS OF TUBERS AND SUGAR FROM THE AMERICAN ARTICHOKE (*HELIANTHUS TUBEROSUS*)[1]

H. B. Sprague, N. F. Farris, and W. G. Colby[2]

THE American artichoke (*Helianthus tuberosus*),[3] which is native to the eastern half of the United States, has considerable potential value as a cultivated crop. Although closely related to the sunflower, the artichoke differs in that it produces tubers as the principal harvested portion. Improved cultivated varieties bear comparatively large tubers clustered near the main root in contrast with wild forms of artichokes which produce small tubers on long stems. The tubers are formed during late summer and autumn, and will store perfectly over winter when left in place in the field.

Artichoke tubers have been used rather extensively for both human food and feed for livestock in France and other European countries for at least a hundred years. Although attention has been directed to the artichoke occasionally in America, its poor storage qualities after harvest have impeded its adoption as a standard crop plant. Nevertheless, the tubers have been recognized locally as a valuable vegetable, and farm experience has substantiated the records of their high feeding value for hogs, dairy cows, and other livestock. Artichoke tubers are also an exceedingly important potential source of levulose sugar. Because of its superior sweetening value and high preservative effect as compared with ordinary cane sugar, levulose sugar has a high potential value in industry and commerce. Development of methods for factory-scale production of levulose from artichoke tubers, will permit exploitation of the crop for levulose manufacture. The present increasing use of artichoke tubers for human food as a vegetable warrants reports of tests on certain cultural practices which are of importance in growth of the crop.

Artichokes are credited with a very wide range of adaptation to both soil and climatic conditions. However, there are certain specific conditions that permit comparatively high yields of tubers and of inulin from which levulose is manufactured. More complete information on such conditions is necessary for profitable production of the crop.

EXPERIMENTAL PROCEDURE

The experiments reported herein were conducted with the improved white variety obtained from T. W. Wood & Sons at Richmond, Virginia. The tubers were cut and planted with a potato planter in early May in rows 3 feet apart,

[1]Contribution from the Department of Soils and Crops, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Journal Series paper of the Agricultural Experiment Station. Received for publication February 28, 1935.

[2]Agronomist and Research Assistants in Agronomy, respectively.

[3]The name "Jerusalem artichoke," frequently applied to this plant, is somewhat misleading since "Jerusalem" is merely an old English corruption of "girasole," the Italian name for the sunflower, with which the artichoke was once confused.

using 8 to 10 bushels of tubers to plant an acre. The growing crop received three to four cultivations prior to July 15 by which time the plants shaded the area between the rows fairly completely. The plants continued vegetative growth until blooming took place in mid-September, and the tops remained green until heavy frosts occurred in October. The tops were then removed by mowing or cutting with a corn binder, and the tubers were dug in November with an ordinary potato digger. Tubers for seed were stored in the ground over winter and harvested the following April just prior to planting.

The field on which the lime and fertilizer experiments were conducted was Sassafras sandy loam which had earlier been cropped to general field crops and later to asparagus with scant fertilization. The fertility was near the average for this soil type under general farming. The individual plats were 50 feet long and 4 rows wide, with rows spaced 36 inches apart. Harvested yields were recorded on the center two rows of each plat. Check plats distributed throughout the field indicated fairly uniform fertility in the area chosen for the test, and the treatments were represented by duplicate plats. The analysis of variance showed that differences of 10.0% in average tuber yields of individual treatments were necessary for odds of 20 to 1. Smaller differences are of course significant when trends are indicated in series of treatments varying regularly in abundance of a single element.

Sugar determinations were made on fresh tubers, or on tubers which were placed in cold storage, and analysed as soon as possible thereafter. The analytical method in 1929 consisted of finely chopping the tubers, direct acid hydrolysis of the carbohydrate, and calculation of the total reducing sugars from weights of the cupric oxide produced by reduction of Fehling's solution with Munson and Walker's tables. In 1930 and 1931, fresh tubers were ground to a pulp from which separate samples were drawn for determinations of moisture and carbohydrates, respectively. The latter samples were acidified with hydrochloric acid and hydrolyzed for 40 minutes at 80°C. The resulting solution was cooled, clarified with lead acetate, made neutral with sodium hydroxide, and filtered. Total sugars were determined from the filtrate, using Lane and Eynon's method.[4]

TUBER YIELDS AS AFFECTED BY SOIL TEXTURE AND RAINFALL

Although the artichoke is tolerant of a wide range of soil texture, the yield of tubers is greatly influenced by this factor in unfavorable seasons. The performance of the crop on two soils is given in Table 1. The rainfall during the period of tuber formation, August 15 to October 15, was deficient in both years, showing an average slightly below half the normal precipitation of 8.0 inches. The low water-holding capacity of the lighter textured soil greatly reduced yields in comparison with a soil of heavier texture. Complete commercial fertilizer was applied at a 1,000-pound rate to both the Sassafras sandy loam and the Sassafras loam soils. From other experiments this amount appears to be in excess of the actual quantity required by the crop. It seems, therefore, that the reduced yields on the light sandy loam were primarily due to the poor water relations of this soil, particularly during the period of tuber formation.

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[4]LANE, J. H., and EYNON, L. Determination of reducing sugars by means of Fehling's solution with methylene blue as internal indicator. Jour. Soc. Chem. Ind., 42 : 32T. 1923.

TABLE 1.—*Relation of soil texture to yield of artichoke tubers and sugar.*

	Light sandy loam soil	Heavy loam soil
Soil conditions:		
Acidity in 1931, pH	6.02	5.6
Field water content Dec. 6, 1934, %	13.8	22.6
Rainfall : Aug. 15–Oct. 15, 1930–31 av., in.*	3.9	3.9
Acre yields of tubers : 1930–31 av., lbs.	10,292	23,005
Acre yields of sugar : 1930–31 av., lbs.	1,995	4,458

*The normal rainfall for this period, when tuber development occurs, is 8.0 inches.

Wide fluctuations in rainfall occurred in the 5 years for which tuber yields are available. Tuber yields (Table 2) were abnormally low on both soils in 1931 when autumn rainfall was only 41% of normal, but the light sandy loam produced only 7,650 pounds in contrast with 16,244 pounds on the heavy loam soil. Maximum tuber yields were obtained on the light soil in the year of liberal rainfall, whereas on the heavier soil no increase in yields resulted from moisture supplies in excess of 4.5 inches for the period of August 15 to October 15. Since the normal rainfall for that interval is 8.0 inches, it seems probable that maximum yields of tubers may be obtained on soils somewhat lighter in texture than heavy loam. In years of normal autumn rainfall, acre yields of 8 to 10 tons of tubers may be expected on strong sandy loam and light loams in this region when the cultural conditions are similar to those in these tests.

TABLE 2.—*Relation of rainfall conditions to tuber yields of artichokes.*

	1929	1930	1931	1932	1934
		Tuber Yields Per Acre, Lbs.			
Light sandy loam	19,020	12,935	7,650	—	—
Heavy loam	—	29,766	16,244	18,876	25,047
		Percentage Total Sugars in Tubers*			
Light sandy loam	14.6	19.9	18.6	—	—
Heavy loam	—	—	19.3	17.9	—
		Acre Yields of Sugars, Lbs.			
Light sandy loam	2,781	2,570	1,421	—	—
Heavy loam	—	—	2,137	3,384	—
		Total Rainfall, Inches			
Aug. 15–Oct. 15†	8.6	4.5	3.3	7.4	12.8

*Total hexose sugar yielded upon acid hydrolysis of carbohydrates.
†The normal rainfall for this period, during which tuber development occurs, is 8.0 inches.

The acre yields of total sugars did not fluctuate as greatly as tuber yields. Sugar content of the fresh tubers increased in dry seasons and fell in moist years, and thus partly compensated for an opposite trend in total tuber weights. Excluding the most unusual year of 1931, the sugar yields varied from 2,570 pounds to 3,384 pounds per acre on the two soils.

The relation of soil moisture conditions to the moisture content of fresh tubers is shown in Table 3. The heavy loam soil with higher water content produced tubers with a moisture content of 75.3%, while tubers from a light soil contained only 70.6% moisture. The skin of artichoke tubers is poorly protected against moisture losses, and the moisture percentage of the tubers at harvest may represent only the current equilibrium between the soil and plant. However, there is no evidence against the possibility that the moisture content of tubers may have been determined during the period of tuber formation.

TABLE 3.—*Relation of soil conditions to moisture content of artichoke tubers.*

	Heavy loam soil	Light sandy loam soil
Soil moisture content Dec. 6, 1934, %	22.6	13.8
Moisture content of tubers Dec. 10, 1934, %	75.3	70.6
Dry matter in tubers, Dec. 10, 1934, %	24.7	29.4

A large part of the variation in sugar content of tubers in a single season is due to differences in the moisture present. The data from six plats in 1931 similarly treated but varying somewhat in soil texture are given in Table 4. The sugar percentage in fresh tubers varied from 16.13 to 20.25. When sugar percentages of the same tubers are expressed on a uniform moisture content of 75%, the sugar values ranged only from 18.06 to 18.77, within the range of experimental error.

TABLE 4.—*Relation of moisture content of tubers to yields of sugar, 1931 yield test on Sassafras sandy loam.*

Plat No.	Moisture content of tubers %	Total sugar content of fresh tubers %	Total sugar content adjusted to basis of 75% moisture in tubers %
1	78.10	16.13	18.40
13	75.45	18.21	18.54
25	73.00	20.25	18.76
26	76.40	17.72	18.77
38	77.34	16.37	18.06
50	73.50	19.65	18.54

The optimum soil texture for artichokes in this region should be considered from the standpoint both of ease of harvest and of total yields. Although light-textured soils facilitate harvesting, heavier soils give greater certainty as to yields. There is some evidence that heavy-textured soils are less favorable than medium sandy loams in wet seasons. In 1934, with an August-October rainfall of 12.8 inches, the optimum yields were obtained on a medium sandy loam in a field with plants spaced 3 feet by 3 feet. On heavy sandy loam grading into loam in texture, the acre yield was 16,833 pounds. Under identi-

cal treatment the medium sandy loam soil produced 19,499 pounds of tubers and the light sandy loam 18,285 pounds. The water relations of the three soils are indicated by the field moisture contents on December 6, 1934, of 14.9%, 12.1%, and 11.0% for the heavy, medium, and light sandy loam soils, respectively. Although the spacing of plants in the row was wider than optimum for high yields, the influence of soil moisture and aeration on tuber formation is shown by the foregoing results. In general, the commercial production of artichokes would seem most desirable on medium to heavy sandy loams or on silt loams and loams that are in a friable condition.

EFFECT OF LIME AND FERTILIZER ON TUBER YIELDS

The production of artichoke tubers on a light sandy loam receiving 12 types of fertilization, with and without lime, was observed for 3 years (Table 5). The response to lime on this soil was perceptible, even though the pH of untreated soil was 5.9. A 2-ton application of ground oystershell lime prior to planting in 1929 increased the average yield of all plats 5.1% for the following 3 seasons. However, with a 4-8-4 fertilizer, the increase from lime was 16.5%. The change in soil reaction which followed liming was not determined until the close of the third crop year at which time the limed plots showed a reaction of pH 6.1. There was a well-defined inverse relation between

TABLE 5.—*Acre yields of artichoke tubers on light sandy loam in relation to lime and fertilizer treatments, 3-year average, 1929–31.*

Fertilizer ratios*	Acre yield of artichoke tubers, lbs.	
	With lime†	No lime
No fertilizer	10,245	9,758
4-8-4	13,849	11,890
4-12-4	13,261	12,132
4-16-4	13,884	10,735
2-8-4	13,522	11,047
4-8-4	13,849	11,890
6-8-4	14,309	13,082
8-8-4	13,345	13,462
4-8-8	11,678	13,047
6-8-8	12,012	13,509
4-8-2	13,636	12,597
4-8-4	13,849	11,890
4-8-6	11,909	12,729
4-8-8	11,678	13,047
8-8-4	13,345	13,462
8-8-6	13,851	14,018
Ave., 12 treatments	12,958	12,334

*Fertilizer broadcast at 500-lb. rate in 1929 and at 1,000-lb. rate in 1930 and 1931. Tuber yields greatly reduced by deficient rainfall in autumn in 1930 and 1931. Average yields for all treatments were 18,511 lbs. in 1929, 12,365 lbs. in 1930, and 7,063 lbs. in 1931.

†Ground oystershell lime applied at 2-ton rate prior to planting in 1929 only.

potash and lime for plats receiving more than 4% of K_2O in the fertilizer. From the standpoint of other crops in the rotation, the use of moderate amounts of lime with 4% to 6% of potash in the fertilizer mixture appears preferable to higher potash without lime on the soil used in these tests. However, for 3 seasons, it was possible to compensate for lack of lime by increasing potash in the fertilizer to 8%.

Although the quantity of fertilizer broadcast before planting was increased from 500 pounds per acre in 1929 to 1,000 pounds in 1930 and 1931, no increase in yield was observed from the heavier rate. This may have been the result of limited soil moisture masking the effect of the fertilizer. However, the excellent yields obtained in 1929 suggest that moderate supply of plant nutrients is adequate for artichokes, in contrast with white potatoes which customarily respond to 2,000 pounds of fertilizer per acre in this region. The highest yield on the lime series, obtained with a 6–8–4 fertilizer, was 14,309 pounds, which was 39.8% above plats receiving lime only. For the unlimed series the highest yield, 14,018 pounds, occurred with 8–8–6 fertilizer, 43.7% greater than that recorded on untreated plats.

Increasing the proportion of phosphoric acid above 8% in the fertilizer ratio did not increase tuber yields. Also, very minor differences occurred with changes in nitrogen percentage. Although fertilizers containing 6% nitrogen were superior on limed plats to those with smaller quantities, fertilizer with 8% nitrogen gave the highest yields without lime. Assuming a value of $10.00 per ton for the tubers, 9 cents per pound of nitrogen, and 3.5 cents per pound of phosphoric acid or potash, the most valuable fertilizer analysis was 6–8–4 on the limed series and 8–8–6 on the unlimed plats. With oystershell lime valued at $6.00 per ton, the 8–8–6 fertilizer without lime was the most profitable treatment in this experiment. When grown in rotation with other crops which respond to lime, it is probable that lime plus 6–8–4 fertilizer would be preferable over a period of years.

SUGAR YIELDS AS AFFECTED BY LIME AND FERTILIZERS

The sugar yields shown in Table 6 are considerably below the values which may be expected in normal years as a result of the exceedingly dry autumns of 1930 and 1931 which retarded growth of tubers and storage of carbohydrates. The sugar yields recorded were calculated from total tuber yields and composition of representative samples treated as described in the early part of this report.

Lime increased total sugar yields 6.8% as an average for all 12 types of fertilization, the difference in individual treatments being as great as 30%. On the limed series, high yields of nearly equal value were obtained under 6–8–4 and 4–8–2 fertilizers. On the unlimed series, the 8–8–6 analysis was significantly superior to all others for the 3-year average. In the last 2 of the 3 test years, however, the 6–8–8 fertilizer proved slightly superior to other analyses. In normal years, it seems probable that 6–8–4 fertilizers with lime or 8–8–6 fertilizers without lime would be the most profitable treatments for sugar production on this soil.

TABLE 6.—*Acre yields of total hydrolyzable sugars from artichokes grown on light sandy loam in relation to lime and fertilizer treatment, 3-year average, 1929–31.*

Fertilizer ratios*	Acre yields of total sugars, lbs.	
	With lime†	No lime
No fertilizer	1,771	1,585
4–8–4	2,385	2,029
4–12–4	2,272	2,163
4–16–4	2,345	1,811
2–8–4	2,237	1,849
4–8–4	2,385	2,029
6–8–4	2,406	2,197
8–8–4	2,237	2,142
4–8–8	1,963	2,164
6–8–8	2,057	2,181
4–8–2	2,479	2,170
4–8–4	2,385	2,029
4–8–6	2,129	2,195
4–8–8	1,963	2,164
8–8–4	2,237	2,142
8–8–6	2,319	2,412
Av. 12 treatments	2,217	2,075

*Fertilizer broadcast at 500-lb. rate in 1929 prior to planting and at 1,000-lb. rate in 1930 and 1931. Sugar yields greatly reduced in 1931 by deficient rainfall in autumn. Average yields for all treatments were 2,726 lbs. in 1929, 2,421 lbs. in 1930, and 1,291 lbs. in 1931.
†Ground oystershell lime applied at 2-ton rate prior to planting in 1929 only.

SUMMARY

Tuber yields of Improved White artichokes at New Brunswick, N. J., were greatly affected by soil texture, presumably through the soil moisture relations during the critical period of tuber formation between August 15 and October 15. Loams were distinctly superior to light sandy loams in dry seasons, whereas sandy loams were superior to heavier types in abnormally wet years.

Yields of 8 to 10 tons of artichoke tubers per acre may be anticipated on strong sandy loam soils or loams in fine tilth in normal years, with a maximum of about 15 tons.

The total hexose sugar (largely levulose) content obtained on acid hydrolysis of tubers ranged from 14.6% in a moist year to 19.3% in the driest season. A large part of the fluctuations in sugar content in a single year is due to variations in moisture percentage of the fresh tubers. The moisture content of tubers is higher when the soil moisture capacity is higher and *vice versa*. The extent of normal fluctuation in tuber moisture with changes in soil moisture at specific locations was not determined.

On a light sandy loam having a pH of 5.9 and relatively low organic matter content, lime and 6–8–4 fertilizer increased tuber yields 39.8% over lime alone and 46.6% over untreated plats; and 8–8–6

fertilizer alone increased yields 43.7% above untreated plats. These were the two most profitable fertilizers, assuming the tubers to have a value of $10.00 per ton.

Increasing the amount of fertilizer from 500 pounds to 1,000 pounds per acre did not increase yields in the test period, indicating a much smaller requirement for plant nutrients than for white potatoes.

Total yields of hexose sugars per acre were greatest with lime and 6-8-4 or 4-8-2 fertilizers, or with 8-8-6 fertilizer alone.

Acre yields of hexose sugar ranging from 2,500 to 3,300 pounds are indicated as average yields in normal seasons on suitable soils.

INHERITANCE OF STEM-RUST REACTION IN WHEAT, II[1]

J. ALLEN CLARK AND GLENN S. SMITH[2]

THIS paper presents further studies on the inheritance of stem-rust reactions of wheat. It is one of a series of papers dealing primarily with the near-immune reaction of Hope and H-44 wheats to stem rust, *Puccinia graminis tritici* Eriks. and Henn. This reaction was transferred from emmer, *Triticum dicoccum* Schr., to hard red spring wheat, *T. vulgare* Vill., by McFadden (4)[3] from a Yaroslav emmer x Marquis wheat cross.

PREVIOUS STUDIES

Clark and Ausemus (2) first pointed out that in the F_1 and F_2 generations of crosses with Hope the near immunity of Hope was inherited as a dominant character, whereas resistance, as in Ceres, was inherited as a recessive character. The dominance was imperfect or incomplete. The F_1 plants of Hope crosses with susceptible varieties had only a trace of rust. In the F_2 generation there was a piling up or a preponderance of plants toward the zero or rust-free end of the distribution.

In 1928, at the annual meeting of the American Society of Agronomy, Clark and Ausemus[4] presented F_3 data showing that in Hope crosses with Marquis and Reliance true-breeding, near-immune, resistant, and susceptible strains were obtained, together with four types of segregation. The results were explained genetically on a two-factor basis. In a Hope x Ceres cross only a single-factor difference was shown. These results were in agreement with those obtained by Neatby and Goulden (5) of Canada.

In 1932, Clark and Humphrey (3) showed that the inheritance in the H-44 x Ceres cross is similar to that in the Hope x Marquis and Hope x Reliance crosses previously reported, proving the two-factor inheritance. A good agreement was obtained for a given genetic interpretation in which it was assumed that Hope had a dominant inhibiting factor for near immunity, that Marquis and Reliance had a major dominant factor for susceptibility, that H-44 carried both of these dominant factors, and that the resistant Ceres carried the double recessives.

On the basis of these previous experiments, and those of other workers, Clark (1) has defined the three differently inherited rust reactions.

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[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Also presented at the annual meeting of the Society held in Washington, D. C., November 22, 1934. The inheritance experiments herein reported have been conducted at the Langdon Substation, Langdon, N. Dak., in cooperation with the North Dakota Agricultural Experiment Station, Fargo, N. Dak. A manuscript giving more of the experimental results is on file in the Library of the United States Department of Agriculture. Received for publication February 27, 1935.

[2]Senior Agronomist and Junior Agronomist, respectively. The writers gratefully acknowledge the help of Dr. H. B. Humphrey, principal pathologist, Division of Cereal Crops and Diseases, for valuable assistance, and Mr. C. G. Colcord, scientific aid, for making the statistical calculations.

[3]Figures in parenthesis refer to "Literature Cited," p. 407.

[4]CLARK, J. A., and AUSEMUS, E. R. Inheritance of immunity from black stem rust, yield, and protein content in Hope wheat crosses with susceptible and resistant varieties. Washington, D. C., 1928. [Mimeographed, 8 p.]

FURTHER EXPERIMENTS

Apprehension has been felt by some agronomists and pathologists regarding the inheritable power of strains descending from Hope and H-44, in further transmitting the near-immune reaction of emmer. Three strains of the H-44 x Ceres, classified in F_3 as near-immune, were crossed with the susceptible Marquis to determine their power in this respect and the modifying effects of small differences between them. It seemed desirable to determine if additional minor or modifying genetic factors are operating that can be established and distinguished from the uncontrolled variations due to environment.

Further results were obtained on these studies at the Langdon Substation, Langdon, N. Dak., in 1934, under conditions of a fairly heavy natural stem rust infection.

MATERIAL AND METHODS

In the H-44 x Ceres cross there were 24 F_3 strains out of 102 grown which were classified as near immune. This was approximately one-fourth of the population. These were not all assumed to be homozygous but to have the genotypes IIss, IISs, or IISS. Only 1 of the 24 strains was entirely rust free in both the F_2 and F_3 generations. In the F_2 generations the plants varied from 0 to 10% and in the F_3 the strains averaged from 0 to 1.8% rust. Three strains selected from these 24 were crossed with Marquis.

The methods were similar to those previously used and are more fully described by Clark and Humphrey (3) and by Smith and Clark (6). In these crosses no infection was obtained in the F_1 generation at Langdon owing to drought, and only a light infection was obtained on the F_2 plants grown in the greenhouse. Random populations were used for the F_3 studies. The populations from each cross were from only one F_1 plant. The plants were classified according to the amount of stem rust in the frequency classes: 0, 2, 10, 20, 30, 40, 50, etc. These frequencies are 10% class centers with the exception of the first two. The 0 class comprises only those plants having no infection. The 2% class includes those plants upon which a trace of rust was present, resembling the F_1 in earlier crosses.

The breeding behavior of the F_3 strains was determined by (a) the distribution in these frequency classes, (b) the average infection, and (c) the standard deviation. The type of curve is shown by the distribution of the amount of rust on each plant in these original frequencies. The average rust percentage and standard deviation of a single observation, or plant, were computed for each strain to analyze them with respect to their average infection and variability. The standard deviation furnishes a measure of dispersion for determining the homozygous and heterozygous strains.

In this study, summaries of the rust data for each cross were made by again distributing the average infection of the strains and parent checks into 5% frequency classes, as 0, 1, 5, 10, 15, etc. The smaller rust classes were used here to obtain a finer analysis for the strains themselves than was necessary when classifying the individual plants within each strain. The 1% class includes those strains the average of which falls within 0.1 and 2.4% rust, inclusive. The 5% class includes strains varying from 2.5 to 7.4% rust, inclusive, etc. From this distribution of the strains in each cross, an average rust percentage for each cross has been calculated, together with its standard error, for the purpose of showing the difference in amount of rust of the three crosses.

The standard deviations of the strains in each cross also have been classified into frequencies, and from this distribution an average standard deviation and its standard error were calculated, making it possible to compare the difference in variability of the three crosses. The standard deviation of a single plant also was calculated for each of the parents so as to compare the variability of the strains comprising each cross with that of their parents. Those strains showing the least variability and having the average nearest to that of each parent are, presumably, homozygous and have the same genotype as that parent with respect to rust.

RESULTS

Conditions at the Langdon, N. Dak., Substation usually are favorable for heavy rust infection, especially when seeding is delayed 10 days to 2 weeks later than usual. However, this delayed seeding was unsuccessful for rust development in 1933 because of drought, and no data were obtained that year. In the season of 1934 some of the 1933 rust experiments were repeated from late seeding so as to test the F_3 classification of 1932 for the less variable strains in the H-44 x Ceres cross classified as near-immune, resistant, and susceptible. The F_3 populations of the three further crosses also were grown.

The 24 strains of the H-44 x Ceres cross, classified as nearly immune in 1932, were grown from bulk seed in 1933. As no rust developed, they were reseeded in 1934 from bulk F_4 seed. The classifications for rust of these 24 strains in F_5, 1934, are similar to those in F_3 except that most of the strains were slightly more variable and average slightly higher in amount of rust, the average for all strains increasing from 0.9% to 2.3% of rust. The one parent strain, C-6–1, that had no rust in both the F_2 and F_3 generations had three plants showing a trace of rust in F_5 and averaged 0.2% of rust. The second parent strain, C-6–2, which had a trace of rust in F_2 and averaged 1.8% in F_3, averaged 4.5% in F_5. The third parent strain, C-10–35, which had 10% of rust in F_2 and averaged 1.5% of rust in F_3, had the greatest infection in F_5, averaging 8.0%. With the exception of C-10–35, the 24 strains were found to have been correctly classified in the F_3.

In addition to the 24 strains classified as nearly immune, other strains of the H-44 x Ceres cross, classified as homozygous resistant and susceptible in the F_3 in 1932, were grown as F_5 in 1934. Comparative results of all hybrid strains classified as homozygous for the three reactions showed that they were with the one exception correctly classified in F_3. In F_5, the resistant strains averaged 17.5% and the susceptible strains 35.3% rust. In this experiment, Ceres had 29.7% and Marquis 49.5% of rust. H-44 and Hope had 0.3 and 0.4% of rust, respectively.

Selections from the zero or rust-free class were made from all of the 24 strains for plant-breeding studies, and three of them, or one from each of the strains C-6–1, C-6–2, and C-10–35, were crossed with Marquis for these further genetic studies. The crosses were made in a greenhouse at the Arlington Experiment Farm near Washington, D. C., in the winter of 1932–33, and the F_1 plants were grown at Langdon, N. Dak., in 1933. The F_2 plants were grown in the greenhouse in the winter of 1933–34 and the F_3 populations at Langdon in 1934.

As the three hybrid strains used for further crossing with Marquis have been found to be no more variable than Ceres or Marquis, and as the rust-free selections from these strains used for crossing resemble the bulk seed in amount and variability of rust, it is assumed that the parent plants were homozygous for rust reaction. On this premise they must have either the near-immune (IIss, IISS) or resistant (iiss) genotypes. The strain C-10–35 resembled some of the resistant strains more closely than it did the other near-immune strains, although it had only 8.0% of rust while Ceres had 29.7% of rust.

The distributions and weighted averages of the parents and hybrids for the three crosses are summarized in Table 1 which shows that the F_3 strains of the three crosses averaged 10.22, 21.16, and 39.94% of rust, respectively. In cross No. 1, 27 strains were in the near-immune range, or 0 to 1% rust class frequencies, and only 4 strains in the susceptible range, or 40 to 55% classes. Cross No. 2 had only 4 strains in the near-immune range and 14 in the susceptible range. Cross No. 3 had no strains in the near-immune range and 48 strains in the susceptible range. In the latter two crosses, however, but few of the strains in the susceptible range statistically equalled the Marquis checks in amount of infection. From these average infections alone, it is not possible to make a satisfactory interpretation of the results for the three crosses. The trends are clearly given, however, and the possibility of recovering the reaction of the parents is shown.

TABLE 1.—*Summary of the stem-rust distributions and weighted averages of the three crosses and parents, 1934.*

Stem rust %	Cross No. 1			Cross No. 2			Cross No. 3		
	C-6–1–2	F_3	Marquis	C-6–2–1	F_3	Marquis	C-10–35–1	F_3	Marquis
0.......	5	1	–	–	—	–	–	—	–
1.......	1	26	–	2	4	–	–	—	–
5.......	–	23	–	3	17	–	–	2	–
10.......	–	21	–	1	10	–	5	2	–
15.......	–	6	–	–	9	–	1	6	–
20.......	–	7	–	–	15	–	–	5	–
25.......	–	4	–	–	11	–	–	2	–
30.......	–	4	–	–	8	–	–	8	–
35.......	–	0	–	–	6	–	–	14	–
40.......	–	2	1	–	6	–	–	6	–
45.......	–	1	1	–	3	–	–	17	–
50.......	–	0	2	–	3	1	–	2	–
55.......	–	1	2	–	1	1	–	9	–
60.......	–	—	–	–	1	4	–	8	–
65.......	–	—	–	–	—	–	–	5	5
70.......	–	—	–	–	—	–	–	1	1
Total....	6	96	6	6	94	6	6	87	6
Average..	0.01	10.22	49.4	3.66	21.16	57.43	10.99	39.94	66.60

The differences between the crosses are further shown by their average rust percentage means and their standard errors as follows:

Cross	M E	Cross	M E	Cross	M E
1	10.22 ± 1.10	1	10.22 ± 1.10	2	21.16 ± 1.45
2	21.16 ± 1.45	3	39.94 ± 1.69	3	39.94 ± 1.69
Difference...	10.94 ± 1.82	-	29.72 ± 2.01	-	18.78 ± 2.22

Since these crosses show such important and significant differences, it seems necessary to assign different genotypic formulas to the parents with respect to their rust reactions.

By using all of the available data on rust, i. e., the original distribution, the average infections, and the standard deviations, it is possible to interpret the results in the broadest sense on a definite genetic basis.

GENETIC INTERPRETATION

In previous studies it has been assumed that a primary factor pair (II) was responsible for near-immunity, which reaction inhibits that of a second factor pair (SS) for susceptibility. Absence of the two dominant factors gives resistance.

The genotypes of Hope and H-44 (near-immune) were postulated as IIss and IISS, respectively, that for Marquis and Reliance (susceptible) as iiSS, and that for Ceres (resistant) as iiss. On this same basis it may be postulated that with respect to the major factors in the present crosses, C-6–1–2 is IIss, C-6–2–1 is IISS, and C-10–35–1 is iiss.

In all cases the phenotype, the genotypic group, and the breeding behavior in the F_3 generation, as indicated by the distribution of the plants of the F_3 strains, are similar to those postulated in the previous paper by Clark and Humphrey (3).

In cross No. 1, C-6–1–2 x Marquis, the segregating and true-breeding strains were separated on the two-factor basis into the seven genotypic groups, previously described, the calculated genotypic ratio being 4 : 2 : 4 : 2 : 1: 2 : 1. The separation was possible by using the F_3 data on distribution, average infection, and standard deviation. For cross No. 2, C-6–2–1 x Marquis, the F_3 strains were separated clearly on a single-factor basis into three groups. These most nearly resemble groups I, IV, and VII of cross No. 1. For cross No. 3, the F_3 strains could again be separated clearly into three groups, or a single-factor 1 : 2 : 1 segregation. These more nearly resemble groups V, VI, and VII of cross No. 1.

On this basis, the goodness of fit for the three crosses is given in Table 2. A good fit is shown for all three crosses.

For the three crosses, 11,941 plants were classified; for the parent checks, 1,354; and for the F_5 strains and parents, 1,538, making a total of 14,833 plants.

TABLE 2.—*Goodness of fit of the three crosses for stem-rust reaction in the genotypic groups.*

Genotypic group	Cross No. 1		Cross No. 2		Cross No. 3	
	Obtained	Calculated	Obtained	Calculated	Obtained	Calculated
I	27	24	23	23.5	—	—
II	14	12	—	—	—	—
III	26	24	—	—	—	—
IV	8	12	52	47	—	—
V	6	6	—	—	16	21.75
VI	11	12	—	—	46	43.50
VII	4	6	19	23.5	25	21.75
Total	96	96	94	94	87	87
Fit	$P = 0.81$		$P = 0.51$		$P = 0.35$	

OTHER CHARACTERS IN RELATION TO RUST

The segregation of hybrids for characters other than for stem-rust reaction may sometimes have a bearing on the segregation and means of the rust character. In these three crosses, the segregation for awnedness and time of maturity appeared to be the other most important characters involved.

AWNEDNESS

All three of the H-44 x Ceres parent strains, C-6-1-2, C-6-2-1, and C-10-35-1, are awned and Marquis is awnleted. The F_1 plants were strongly awnleted. The random populations in F_3 were classified for awnleted, segregating, and awned strains. The data show a close agreement to a single-genetic factor difference, or a 1 : 2 : 1 ratio, for the awnleted, segregating, and awned strains. For cross No. 1 the obtained numbers were 29 : 39 : 28 and the calculated numbers on the theoretical ratio of 1 : 2 : 1 would be 24 : 48 : 24. This shows a satisfactory agreement ($P = 0.19$). The agreement is closer for cross No. 2 ($P = 0.85$) and the same for cross No. 3 ($P = 0.19$).

In cross No. 1, the awnleted strains averaged lower in rust than the awned, although their percentage difference, 2.98 ± 2.84, is not significant. For the three crosses there was no consistent, important, or significant difference between the awnedness classes and percentage of stem rust.

TIME OF MATURITY

Notes on date of heading and date of maturity were taken on the F_3 strains and parent check rows. The strains headed from July 10 to 20 and matured August 10 to 17. The rows were harvested and classified for rust on the dates of maturity and before the plants had dried. The dates of heading and maturity were very similar and about a month apart. Cross No. 1 was earlier than cross No. 2 by 2.41 ± 0.15 days. There were no significant differences in time of maturity be-

tween cross No. 2 and cross No. 3. Correlation coefficients calculated for date of maturity and percentage of stem rust for the three crosses are $+ 0.283 \pm 0.094$, $- 0.057 \pm 0.103$, and $- 0.252 \pm 0.100$, respectively. For cross No. 1 earliness was positively and significantly correlated with rust reaction, the earlier strain having the least rust. In cross No. 2 there was no relationship, whereas in cross No. 3 there was indicated a negative relation.

DISCUSSION

A similar inheritance for cross No. 1, C-6-1-2 x Marquis (IIss x iiSS), with that of the H-44 x Ceres cross (IISS x iiss) and that of the Hope x Marquis (IIss x iiSS) is shown. This should allay any apprehension regarding the power of strains descending from Hope and H-44 to transmit the near-immune reaction from stem rust. This is the third cross through which it has been transmitted from emmer. The results further support the previously postulated two-factor inheritance with one dominant inhibiting factor for near-immunity and one major dominant factor for susceptibility, with the resistant reaction being recessive to both.

Cross No. 2, C-6-2-1 x Marquis (IISS x iiSS), apparently is principally controlled by the near-immune factor, although the cross shows a greater total range and a larger average standard deviation. The C-6-2-1 parent also carries more rust than H-44, which is assumed to have the same genotype. The small variation shown in the C-6-2-1 check rows and their similarity to the bulk seed of C-6-2 in F_3 and F_5 support the premise that it is a homozygous strain.

Cross No. 3, C-10-35-1 x Marquis (iiss x iiSS), is principally controlled by the one susceptible factor. The strain C-10-35 undoubtedly was incorrectly classified in F_3. While the parent strain C-10-35-1 carries much less rust than Ceres, it is assumed to have the same resistant genotype (iiss). The piling up of the strains toward the susceptible end of the distribution and the lack of any near-immune strains furnish evidence that it is properly classified as resistant. The shortage of resistant strains and the excess of susceptible strains in the single-factor segregation further support the premise that the parent strain was homozygous for the recessives of the two major factors.

Uncontrolled variations due to environment appear to be the principal causes of certain inconsistencies in the interpretation of the results in the three crosses, although there is conflicting evidence indicating that there may be additional minor factors for susceptibility that could account for the differences between Ceres and C-10-35-1 and between certain of the resistant hybrid strains. If these and other small differences are consistently repeated from season to season or from place to place, there will be strong circumstantial evidence of additional genetic factors. No additional genetic factors, however, can be directly established from the results of these crosses. From further study of a cross between C-10-35-1 and Ceres, it might be possible to establish an additional minor factor for susceptibility. There is no evidence, however, of an additional minor factor or factors for near-immunity.

SUMMARY

The inheritance of the three stem-rust reactions—near-immunity, resistance, and susceptibility—has been further studied in hybrids. Earlier crosses were interpreted as showing that Hope has a single dominant inhibiting factor for near-immunity, that Marquis and Reliance have a major dominant factor for susceptibility, that H-44 carries both of these dominant factors, and that the resistant Ceres carries the double recessives.

Three further crosses are interpreted as showing that the same major factors principally control the inheritance. No additional minor or modifying factors could be directly established from the results of these crosses. Certain variations and inconsistencies in the interpretation are considered about as likely due to variations caused by environment as to additional minor or modifying genetic factors. The rust genotype of strain C-6–1–2 is postulated as IIss, similar to Hope; strain C-6–2–1 as IISS, similar to H-44; and strain C-10–35–1 as iiss, similar to Ceres. The rust reactions in cross No. 1, C-6–1–2 x Marquis (IIss x iiSS), are controlled by the interaction of two major genetic factor pairs, the near-immune factor inhibiting the susceptible factor. Cross No. 2, C-6–2–1 x Marquis (IISS x iiSS), is principally controlled by the one near-immune factor pair and cross No. 3, C-10–35–1 x Marquis (iiss x iiSS), by the one susceptible factor pair.

These further studies confirm the results from the earlier crosses on the inheritance of stem-rust reactions in wheat.

LITERATURE CITED

1. CLARK, J. A. Inheritance of stem rust and bunt reactions in spring wheat crosses. Proc. World's Grain Exhib. and Conf. 2. (In Press.)
2. ————, and AUSEMUS, E. R. Immunity of Hope wheat from black stem rust inherited as a dominant character. Jour. Amer. Soc. Agron., 20 : 152–159. 1928.
3. ————, and HUMPHREY, H. B. Inheritance of stem-rust reaction in wheat. Jour. Amer. Soc. Agron., 25 : 497–511. 1933.
4. MCFADDEN, E. S. A successful transfer of emmer characters to *vulgare* wheat. Jour. Amer. Soc. Agron., 22 : 1020–1034. 1930.
5. NEATBY, K. W., and GOULDEN, C. H. II. The inheritance of resistance to *Puccinia graminis tritici* in crosses between varieties of *Triticum vulgare*. Sci. Agr., 10 : 389–404. 1930.
6. SMITH, G. S., and CLARK, J. A. Inheritance of stem-rust reaction and correlation of characters in Pentad, Nodak, and Akrona durum-wheat crosses. U. S. D. A. Tech. Bul. 385. 1933.

EFFECT OF FERTILIZERS ON THE LENGTH OF COTTON FIBER[1]

E. B. REYNOLDS AND R. H. STANSEL[2]

PREVIOUS work at the Texas Agricultural Experiment Station has shown that application of complete fertilizers to cotton on Kirvin fine sandy loam and Lufkin fine sandy loam, both of which respond to applications of phosphoric acid, had no appreciable effect on the length of fiber.[3] In a few instances, however, applications of phosphoric acid on the Kirvin fine sandy loam soil produced increases in the length of fiber, which, although statistically significant, were not large enough to be detected consistently in the commercial classing of cotton.

It was thought desirable to make additional studies on other soils low in phosphoric acid to determine whether fertilizers have any effect on length of fiber. Accordingly, studies were made on Lake Charles clay at Texas Substation No. 3, Angleton, on which cotton responds readily to applications of phosphoric acid. The work was conducted in 1932 and 1933, but the test in 1932 was destroyed by a tropical hurricane on August 13, thus results are available for 1933 only.

METHODS

The work was done with cotton in a 3-year rotation of cotton, cotton, and corn. The following fertilizer treatments applied under the cotton before planting were used: At the rate of 400 pounds per acre, 0–4–0, 0–8–0, 4–0–4, 4–12–4; 0–12–4, 8–12–4; and 4–12–0; and at the rate of 800 pounds per acre, 4–12–4, 8–12–4, and 8–12–8.

After the cotton had emerged to a good stand and had reached a height of about 4 inches, it was thinned to one plant every 12 inches in the row, previous work having shown this to be a satisfactory spacing for the region. When the cotton began to bloom actively, about 250 blooms were tagged on each plat on the same day. The bolls resulting from these tagged blooms developed under the same weather conditions. When the bolls had matured and opened they were cut from the plant, the bolls from each plat being placed in a separate bag. The number of bolls harvested ranged from 43 to 85 for each plat.

The length of lint was obtained by combing the fiber on the second pair of seeds of a normal lock from every boll harvested. The combed lint was removed from the seed, placed on a black velvet board, and measured to the nearest millimeter. A statistical analysis of these data was made by Fisher's method[4] of comparing two means.

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[1]Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Texas. Technical Paper No. 316. Received for publication March 4, 1935.

[2]Chief in Agronomy and Superintendent of Texas Substation No. 3, respectively.

[3]REYNOLDS, E. B., and KILLOUGH, D. T. The effect of fertilizers and rainfall on the length of cotton fiber. Jour. Amer. Soc. Agron., 25 : 756–764. 1933.

[4]FISHER, R. A. Statistical Methods for Research Workers. London : Oliver and Boyd. Ed. 4. 1932.

EXPERIMENTAL DATA

The work was planned so as to have four replications of each treatment. Due to an error in the field, however, data were obtained on only three plats which received 400 pounds per acre of the 4-12-4 fertilizer (used as soil checks) and on one plat each of the other treatments. The length of the fiber from each of the three check plats was compared with that from the other two check plats and the results of the other treatments were compared with the results of the nearest check plat.

A comparison of the results of the three check plats (M-25, M-30, and N-25), which received the 4-12-4 fertilizer at the rate of 400 pounds per acre, shows that there was practically as much difference in length of fiber between these plats as there was between any of the treatments. The fiber on check plats M-30 and N-25 was significantly longer than the fiber from check plat M-25, as shown in Table 1. Plat M-30 produced fiber 26.64 mm long, which was 1.18 ± .32 mm longer than the fiber from plat M-25. This difference is highly significant, with P .0002, which means that a difference as great as this would occur only about twice in 10,000 times due to chance alone. Further, plat N-25 yielded fiber 26.56 mm long, which was 1.10 ± .26 mm longer than the fiber from plat M-25. This difference also is highly significant. These differences in length of fiber on three uniformly treated plats indicate that something other than the fertilizer treatment caused these differences in length of fiber.

The length of fiber from the plats treated with 800 pounds of 4-12-4, 8-12-8, and 8-12-4 were compared with the length of fiber from plat M-25, the nearest check plat. The plat which received the 4-12-4 fertilizer at 800 pounds per acre produced fiber 26.49 mm long, or 1.03 ± .26 mm longer than that from plat M-25 (Table 1). This wide difference is highly significant. The plat which received the 8-12-8 fertilizer also yielded fiber significantly longer than plat M-25.

Of the five comparisons with check plat M-30, only two significant differences in length of fiber were obtained (Table 1). Plat M-30, which received the 4-12-4 fertilizer at 400 pounds per acre, produced fiber significantly longer than the fiber from plats treated with the 0-12-4 and 8-12-4 fertilizers.

The other check plat, N-25, yielded fiber that was significantly longer than the fiber from the unfertilized soil or from the 4-12-0 treatment (Table 1).

DISCUSSION OF RESULTS

Of the 13 comparisons on length of fiber given in Table 1, six differences are highly significant and two others significant, considering P .05 (odds 19 : 1) as significant. The mean difference in length of fiber in the other comparisons was not significant. The greatest absolute difference in length, 1.38 mm, was found in the fiber from the plats treated with the 4-12-4 fertilizer at 400 pounds per acre and the 8-12-4 fertilizer at 800 pounds per acre. This difference is highly significant for the probability is that a difference as great or greater than this would not occur once in 10,000 times due to chance alone.

TABLE 1.—*Statistical significance of mean difference in length of cotton fiber from plats receiving different fertilizer treatments.*

Comparison of treatments	Length of fiber, mm	P
	Comparison of Check Plats	
4-12-4 (M-30)	26.64 ± .27*	——
4-12-4 (M-25)	25.46 ± .18	——
Difference	1.18 ± .32	.0002
4-12-4 (N-25)	26.56 ± .18	——
4-12-4 (M-25)	25.46 ± .18	——
Difference	1.10 ± .26	< .0001
4-12-4 (M-30)	26.64 ± .27	——
4-12-4 (N-25)	26.56 ± .18	——
Difference	.08 ± .32	.8026
	Comparisons with Check Plat M-25	
4-12-4 (800 lbs.)	26.49 ± .19	——
4-12-4 (M-25)	25.46 ± .18	——
Difference	1.03 ± .26	< .0001
8-12-8 (800 lbs.)	26.06 ± .22	——
4-12-4 (M-25)	25.46 ± .18	——
Difference	.60 ± .28	.0324
4-12-4 (M-25)	25.46 ± .18	——
8-12-4 (800 lbs.)	25.26 ± .17	——
Difference	.20 ± .25	.4238
	Comparisons with Check Plat M-30	
4-12-4 (M-30)	26.64 ± .27	——
0-12-4	25.76 ± .17	——
Difference	.88 ± .31	.0046
4-12-4 (M-30)	26.64 ± .27	——
8-12-4	25.32 ± .19	——
Difference	1.32 ± .32	< .0001
4-12-4 (M-30)	26.64 ± .27	——
0-4-0	26.46 ± .21	——
Difference	.18 ± .34	.5962
4-12-4 (M-30)	26.64 ± .27	——
0-8-0	26.12 ± .20	——
Difference	.52 ± .33	.1142
4-12-4 (M-30)	26.64 ± .27	——
4-0-4	26.13 ± .25	——
Difference	.51 ± .37	.1676

*The standard error and not the probable error is used here.

TABLE 1.—*Concluded.*

Comparison of treatments	Length of fiber, mm	P
	Comparisons with Check Plat N-25	
4-12-4 (N-25)	26.56 ± .18*	——
4-12-0	25.73 ± .24	——
Difference	.83 ± .30	.0056
4-12-4 (N-25)	26.56 ± .18	——
No fertilizer	25.65 ± .20	——
Difference	.91 ± .27	.0008

*The standard error and not the probable error is used here.

As shown above, there were some significant differences in the length of fiber between several of the fertilizer treatments. These differences, however, do not seem to be related in any way to the amounts of nitrogen, phosphoric acid, or potash, or to the total amount of fertilizer. Since there was practically as much difference in length of fiber between the three uniformly treated check plats as there was between any of the fertilizer treatments and since there was no consistent relation between the amounts of nitrogen, phosphoric acid, or potash, or amounts of fertilizer, and the length of fiber, it seems reasonable to conclude that the differences in length of fiber were due to something other than fertilizer treatments.

SUMMARY

In previous work to determine the effect of fertilizers on length of fiber, the application of phosphoric acid to cotton on a soil that responds readily to phosphoric acid apparently increased the length of fiber. An experiment using 10 different fertilizers was conducted in 1933 on Lake Charles clay soil, which is low in phosphoric acid, to study the matter further. Some significant differences in length of fiber were obtained from the variously treated plats, but the differences apparently were not caused by differences in the amounts of nitrogen, phosphoric acid, or potash, or to different rates of application of the fertilizer.

AGRONOMIC AFFAIRS

KORSMO'S WEED PLATES

PROFESSOR Emil Korsmo of Oslo, Norway, the recognized authority on weeds in Europe, has now made his 30 colored weed plates available. These plates are from paintings that were made in Korsmo's own laboratory. They are life size and are 84 x 64 cms and show the plants from seed to full development. The scientific name is given in all cases as well as the most common name used in England, Germany, France, and Norway. A booklet describing the entire set comes with the set of plates. The charts come in two forms, on sheet form paper and on leather paper with cloth edges and eyelets. The price of the former is RM 22 and the latter RM 38, with a duty of 25%. The leather paper with the eyelets for convenient hanging is to be recommended. They may be gotten through Koehler and Volckmar A.-G. and Co., Leipzig, Germany.—A. L. BAKKE, *Iowa State College, Ames, Iowa.*

NEWS ITEMS

THE ANNUAL summer meeting of southern agronomists will be resumed this year. The 1935 meeting will be held in Virginia sometime in August. The exact dates and an itinerary will be announced in the July issue of the JOURNAL.

President H. K. Hayes has received a communication from Dr. Franco Angelini announcing the sixth General Assembly of the International Federation of Technical Agriculturists to be held in Brussels on July 31. Also in Brussels, on July 26 and 27, will be held the first International Congress of the Agricultural Press; and on July 30, the fourth annual International Conference of Agricultural Teaching.

ACCORDING to *Science*, Dr. C. R. Ball has been named Executive Secretary of the Advisory Council for the federal government in the project to develop the economic and social resources of the Tennessee Valley. Apart from power generation and distribution, the Tennessee Valley project embraces rural rehabilitation and ranges from erosion control to wild life preservation.

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THE INTERDEPENDENCE OF AGRONOMIC RESEARCH AND RESIDENT AND EXTENSION TEACHING[1]

J. S. OWENS[2]

THE early history of our agricultural colleges is the story of the achievements of a few men. They were men of ability, usually well trained in science. While it may be true that their success was due in part to the contributions which science could make in its virgin applications to agriculture, it is worth while looking for other factors. The early leaders started with problems which were closely associated with agricultural practice. They knew them first hand; they often performed every operation in their own investigations; they were in frequent association with farmers and usually with classroom students as well. Only a little time was required for keeping abreast with the investigations being conducted by other workers. The problems which have arisen with expansion of organizations and higher specialization could not have existed. Each worker could develop his own work; he bore the responsibility for it; he was unencumbered with the *impedimenta* which now result from many regulations and the difficulties of correlating relationships between several closely related fields of knowledge.

The only discussions of these problems which have been found are those reported in the recent *Proceedings* of the annual meetings of the Land-Grant College Association. They have been confined almost exclusively to problems of administration and have ignored completely the one factor which seems to be reaching an end point in teaching an applied science; the continuation of a scholastic attitude and a comprehensive acquaintance with the rapidly developing information. The explanation may be that only administrators have been sufficiently interested to attempt making a contribution. However, they have been interested in functioning machinery. The problems incident to broadening knowledge and specialized duties need examination by those who are closest associated with them. They are in the best position to determine the real worth of their endeavors.

[1]Contribution from the Department of Agronomy, Connecticut State College, Storrs, Conn. Also presented before the Northeastern Section of the American Society of Agronomy in joint session with Section O, A. A. A. S., and the Potato Association of America, December 29, 1934, Pittsburgh, Pa. Received for publication May 4, 1935.

[2]Professor of Agronomy.

The agronomy field is a particularly suitable one for studying recent trends in administration, and in functional separation and their ultimate consequences. The field has been growing. Occasionally, some group comprised mainly of investigators feels their problems so vital and different that they wish to "separate," and form a new organization because they believe they have developed a *new science*. Contributions, particularly in soils, concern all plant production and not farm crops alone. Likewise, plant and chemical developments, outside the narrower field of agronomy are seemingly increasing at a geometrical ratio and they may mean more to farm crop production than those made by the more strictly farm crop research. The extension teacher sees farm situations becoming more intricate constantly. The fund of information has become so vast that even the light of twilight has passed for the extension specialist who attempts to keep abreast of the information which has agronomic relationships.

It will be assumed for this discussion that extension is education and not promotion to effect the perpetual existence of an organization. While this assumption may have been widely accepted the difficulties involved in its continuation have received scant attention. If the goal is superficial work of temporary value, we need only page the advertising expert.

Much research has necessarily become more and more remote from its practical, or at least from its direct and immediate, use. The simple, almost obvious, comparisons and confirmations have, in the main, been completed. Research requires highly developed technic and special skills. Limitation of time alone makes close observation of farm problems difficult. Sometimes, too, the research worker does not possess the personal qualifications necessary for interpreting and popularizing his own discoveries. Research and teaching tend to separate. They continue growing further apart.

Through its many contacts, extension has developed into an advertising agent for the entire institution. Since it is becoming more remote from the masses, research is becoming more dependent upon extension for creating support. On the other hand, because extension demands comprehensive training and experience, it continues drawing upon research staffs for personnel.

What are some of the possibilities for meeting the problems which have been suggested? Suppose we consider starting with the specific problem to be solved and adjusting plans to it. This is what the earlier workers did. Does the problem originate from a real need? Will it involve laboratory, field plat, or farm studies? What person or persons are most capable for conducting the experiments? If the problem is a large one, will the one who is most familiar with the problem have an opportunity to explain its meaning to the farmers of the state?

The following seems a more common procedure. A member of the research staff, others have little or no opportunity, feels that he must undertake a new project. It may be his pet hobby or something which would appear to make a good showing. This is not meant to suggest that only problems which have visible economic value should be undertaken.

After valuable, and sometimes not valuable, conclusions are reached, bulletins intended for professional colleagues are written. The extension worker may not see "practical" use, or what is more probable, he is so busy with many little things that he passes over the matter entirely. Even if the problem seems important to the extension program, the specialist cannot have the same understanding and enthusiasm about its meaning as the one who did the work.

The illustration just given was meant to suggest division upon a problem basis instead of upon a method or "job" basis. There are difficulties involved, but its use is worth more consideration. How could it be worked out? Assume that pasture production is of great importance in a state and that there are many serious problems associated with it. One man might, with some assistance, conduct the research at the college, outlying fields or substations, supervise demonstrations, write popular as well as technical interpretations, and lead the whole teaching program in resident and extension.

Such a plan probably would mean reorganization of our institutions, but present divisions are not sacrosanct; they are the result of laws made before experience was secured and before the problems became so intricate. The real difference is in the importance of the machinery and the product which the machine should be designed to produce.

It may seem idle to suggest closer relationship between workers with present organizations. Yet some institutions are broken up, extension specialists are some distance from the others and, in some instances, research headquarters are away from the college campus. Formal conferences may be necessary with larger staffs, but they cannot replace frequent informal contacts.

Administrators are obligated to help in creating a spirit for cooperation by removing causes for petty jealousies and in securing freedom from unnecessary regulations and interference.

It is conceivable that more interchange of duties could be developed. Extension programs might be interrupted slightly, but the work become more effective in the end. The extension worker might teach a course occasionally or conduct certain investigations. The interchanging would be refreshing, give more opportunity for study, and develop a mutual appreciation of the difficulties in the other types of work. Incidentally, it might help in keeping all divisions on an equal basis.

Under any organization, the leader in one division cannot dictate the procedure for the leader in any other. The extension worker, for instance, should know more about his problems than his research associate and *vice versa*. Yet, the research worker should know the extension problem and be given opportunity to analyze and to offer criticisms.

Little attempt has been made to answer the problems raised. Any which are adequate would seem to be based upon the following questions: With the increasing fund of agronomic knowledge and growing complexity of problems, can the teacher, more particularly the extension teacher, continue covering large portions of the field, or as is often the case, the entire field of agronomy? Can research afford

to become further and further removed from the source of the problems which are the occasion for its existence? Is any division of work which does not offer opportunity and stimulation for a continued high plane of scholarship satisfactory for any particular type of the work and consequently for all?

HELPS TO EXTENSION WORKERS IN DETERMINING THE NEEDS OF SOILS AND CROPS[1]

Ernest Van Alstine[2]

WHAT is stated here on the subject of chemical soil tests is from the viewpoint of one who is interested more particularly in the production of dairy crops and general farm crops rather than in market gardens or greenhouse crops.

If it is the purpose of this paper to "start something", it is hoped that it might be a fuller realization of the pressure under which most agricultural extension workers and especially the county agricultural agents work and their impatience to get on with committee meetings, correspondence, circular letter releases, news articles, farmers' meetings, demonstrations, program making, membership drives, reports, exhibits, keeping up on the newest information along all lines of agriculture, and innumerable other things of which these are only a suggestion, all of them, however, important and necessary to the continuation of their jobs and the good they hope to accomplish.

It is hoped that it might be possible to start some accurate thinking along the line of the difficulties in the way of the county agent giving careful persistent study to such intricate problems as that of soil chemistry. It is also desired to direct attention to those sources of information available to county agents for which they may not be receiving full credit.

The problem of the experimenter in soil fertility is not quite that of the agricultural extension agent or the extention specialist. The research worker studying soil fertility problems wants to know what plant nutrient is deficient or which one or more plant nutrients will give crop responses when used on a particular soil under definite, known conditions and for a particular crop. From this point he may generalize, or perhaps he may set up another experiment.

The extension worker on the other hand, wants to know what answer to make to each of 50 to 500 or more farmers who are asking what kind and amount of fertilizer will give satisfactory results for a variety of crops when used on one to a dozen fields varying in soil types and differing in their past lime and fertilizer treatments. If the handicaps to the "extensioner" could stop here the problem would not be so difficult, but he must be able to give his answer for the unknown moisture and temperature conditions of the coming season with no assurance of the cultural care that will be given the crop and no very accurate guide as to the value of the crop after it has been grown. Moreover, the answers must be given between the spring thaw and crop planting time, in many instances between spring plowing time and seeding. This is also the time of year when

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Also read before the Northeastern Section of the American Society of Agronomy at Pittsburgh, Pa., December 29, 1934, in joint session with Section O, A. A. A. S., and the Potato Association of America. Received for publication February 15, 1935.

[2]Extension Professor.

there are a thousand and one other things for both the county agent and the extension specialist to be doing.

The answer for each field must be right, not only in a majority of cases or in 75 or 80% of the cases, but if a county agent is to keep the loyal support of his farmers he must be right in close to 100% of the cases. He should not be expected to answer everything, but he should be right in the answers that he does make. Certainly when he tells one of his farm bureau committeemen or a county supervisor that he should buy a particular kind of fertilizer to get good results with a certain crop, he must be sure that this particular case is not one of the 20% that fails while a neighbor gets as good or better results without advice of the county agent and at less expense.

Let us look at some of the difficulties that face a county agent in his attempt to use a chemical soil test. In the first place, it is recommended by those who have made most use of chemical soil tests that in order correctly to diagnose the need for any one element of plant nutrients, some knowledge is necessary as to the sufficiency or overabundance of each of the other 9 to 14 things for which chemical tests have been devised and advocated. Some of this information is available for most soils without making tests, such, for instance, as the absence of sodium and chlorine in harmful amounts on well-drained soils, but there still remain to be made more tests than any county agent can make. He does not have the time for it and few county agents are properly trained for making such tests. He does not know how to go about the work nor how to take the precautions necessary in making reliable tests. Not only does he lack the training, but he also lacks the incentive, the desire, and the opportunity to acquire the necessary information without falling farther behind in some of the things that to him seem to give greater promise of valuable returns for the time and effort expended.

In the second place, few farm bureau offices are equipped or can be equipped to do chemical work. Such testing equipment as is in use for determining lime requirement is often cared for and handled in such a way that a chemist would wonder how reliable results could be secured. Office clerks are frequently called upon to make the lime requirement tests.

In the third place, with 10 chemists testing a single soil the results would probably agree *fairly well*, provided they all used the same methods. If they were all agronomists as well as chemists, we wonder how many different recommendations there would be for the same crop. With tests by 40 or 50 different county agents or their assistants, how many different kinds of recommendations might be expected?

The average county agent is not a chemist and he is not going to be one regardless of our wishes in the matter. Not only that, but altogether too many of them lack the scientific information regarding soil fertility and soil chemical activity which is essential for them to be able to make recommendations on the basis of chemical tests.

In order to make such interpretations we find in the literature on soil testing, and we fully agree with it, that careful consideration must be given to the following:

1. The nature of the crop to be grown.
2. Root penetration and extent, whether as a result of plant habit of growth or as a result of physical soil condition, ground water level, or something else.
3. Climatic conditions, including temperature, humidity, and water supply.
4. The deficiency or overabundance of other plant nutrients and plant toxins.
5. Any and all other factors limiting plant growth.
6. Physiological problems influencing plant growth such as the substitution of sodium for potassium, the utilization of ammonium in place of nitrate nitrogen and others.

If a skilled, scientifically trained chemist-agronomist, or agronomist-chemist, after due consideration of all necessary factors which may influence the drawing of proper conclusions, is able to hit the nail squarely on the head in only 80% of the cases and thinks he is doing very well indeed if he misses only 1 out of 10, what is to be expected of an overworked (or overharassed if you prefer) county agricultural agent who is entirely untrained, unskilled, and unpracticed in that sort of thing? Experience leads us to believe that he will either play with the tests for a time until he learns how time-consuming and difficult of proper interpretation the whole thing is and then give it up entirely, or he will continue to test soils and make recommendations merely on the basis of the test alone, never realizing the limitations of the tests nor knowing how many times his recommendations are no better than the farmer's guess.

As an illustration of what is meant, mention might be made of some tests for determining lime needs of a soil for alfalfa. Apparently some workers are able to distinguish differences as low as 500 pounds of limestone to the acre in the needs of the plowed soils and make recommendations accordingly. This is probably well within the limit of error in evaluating the influence of other factors upon the effectiveness of any reasonable amounts of lime that may be used.

It may be suggested that the extension specialist should make the interpretations of the results secured by the county agent, but it is difficult enough to interpret one's own results without attempting those of some one else, and the writer for one should not want to try it.

It is very difficult if not impossible for any specialist to get the information necessary to go with chemical tests for interpretation and recommendation on soils sent to him or soils collected by himself. It might be possible for an agent to get this information and the soil samples and forward both to some one qualified to make tests and recommendations. Such a person would certainly be busy trying to get recommendations back to the county agents of a state like New York, Pennsylvania, or even the smaller states. We wonder, too, if in any event, he would be earning his money if he got many samples taken merely for the sake of impressing farm bureau members with the state service available to them. There would be plenty of samples taken for no other purpose even as there now are when agents do their own testing and for lime requirement only.

Over against these handicaps of the county agent in making and interpreting chemical soil tests there are many guides which the agent may see and follow to a high percentage of accurate recommendations, guides which a good man but one who is not spending his life and effort in that particular county cannot even see. A county agent has the possibility of the following helps in formulating a fertilizer recommendation:

1. A knowledge of farmers' results with different fertilizers on similar soils and for the crops in question.
2. The advantage of any field experiments on the same or similar soils in the county or state.
3. Direct information from the farmer he hopes to serve about treatments and responses on the field in question.
4. An opportunity to study the field and the soil in place.
5. The possibility of gaining some information about the farmer's practices, his weed problems, and his financial condition.

It is seldom that a county agent is not able after a few years of service to say that the soils in this locality must be limed for alfalfa or for clover, or that the soils in that section respond to superphosphate more than to anything else, or that potash is needed here.

It is true that he should have all these advantages when attempting to interpret chemical soil tests, but I think you will agree that his object is to get the information necessary to a proper recommendation. If he can make such a recommendation from the kind of information he has or knows how to get easily, information he is well fitted to interpret, it may not be so important that he go much farther.

It may be observed that in the development of the various soil tests comparison is made of one method with another, and the best criterion for reliability of a test is the degree of agreement secured with field results where yield records have been kept. Where field records are available or where response to liming and fertilizing can be observed on fields and farms for which information is wanted it is most desirable, and chemical tests that do not agree with such field observations are properly discarded.

This is not to say that the tests should be done away with or that they are unnecessary and of no value, even though a reading of the literature on soil testing gives one the impression that there has been considerable analytical target practice to see who could come closest to the mark set up by field results and quite a number of shots go wide of the mark. The literature reveals, too, a wide difference of opinion as to who is the best marksman or whose system shoots best.

The tests are valuable and should be used when and where they can be properly made and interpreted by some one who knows their limitations and their significance. The writer knows of no better way to locate the probable reason why some soils do not respond to any of the generally recommended treatments. Had a certain city made use of some of these tests in advance, it might have saved considerable expense when it was found after spending a great deal of money and effort on a park system that the soil was so impregnated with salt that nothing would grow on it.

If these soil tests are made by some one who can devote enough of his time to the work so that results may be considered reliable, and if with their help a study can be made of soil types, or of soils having similar properties, and if this information of general application for particular soils can be made available to county agents in empirical but usable form and to the extension specialists in a way to make more intelligible to them observed responses or lack of responses to soil treatments, then they will serve a very useful purpose. The co-operative effort of an extension specialist in crops and a soil analyst would result in much good. It is difficult, if not impossible, for one man to perform the functions of both. Probably the wholesale use of soil analyses made yearly or separately on the same fields as would be requested by farmers who think they can get from a test tube the answer to their fertilizer problems would be not only unnecessary but unwise.

What is needed among the field men is a fertilizer program for the important soil types of a state, a fertilizer program arrived at by preliminary soil analyses, by field tests with different fertilizing and cropping methods, by out-of-door cropping tests in frames, or by greenhouse culture tests with the various soils. Fertilizers and lime need to be tried on the different kinds of soils to learn their greatest needs. If we then have the past record of a particular field for the soil of which we have this information, it should be possible to advise a lime and fertilizing program that will be accurate for a rotation or for a period of years. Whether a man should lime this year or wait until next may not and often does not depend so much upon the condition of the soil as revealed by a chemical test as it does upon the farmer's financial condition. That is especially true for such conditions observed a number of times when county agents, and good agents too, have told farmers that they could not grow alfalfa without first liming (advice given presumably so as to be on the safe side), and yet in spite of a lack of the lime because of inability to pay for it, the seedings were made with excellent results.

If a soil needs phosphorus this year it will probably need it next. At least it should be applied in amounts as great as those removed in crops.

Training schools for extension field men are needed to teach them to interpret observations that may be made on the soil without a chemical analysis. They need instruction in making observations so they may be able to see what should be, but often is not, plainly evident. More thorough training in certain phases of soil physics, in the principals of soil chemistry and in soil mapping or the basis for soil type classification is needed. A little more of the geology of soils and of soil biology and the influences these factors have upon plant growth and crop production is also needed.

When county agents are well grounded in these fundamentals, they will be better able to give good advice on soil fertility problems and will be less likely to misinterpret chemical tests when they are properly made by some one who knows how to make them.

A COORDINATED PROGRAM FOR RESEARCH AND EXTENSION[1]

C. H. MYERS[2]

THE committee responsible for the formulation of this program was influenced, according to a statement by the secretary, by "considerable criticism both from members and from non-members of the Northeastern Section of the American Society of Agronomy pertaining to the lack of agreement and cooperation between the research and teaching agronomists and the extension agronomists."

Those invited to discuss the problem were advised by the committee to speak frankly to the end that constructive thought and action might be stimulated. It is in accordance with this spirit and attitude that the writer has accepted the opportunity to present the problem as viewed by one engaged in research and teaching.

At the very outset it is fair to accept the premise that the relationships between those engaged in research and extension are not all that they should be, in spite of the very significant contributions that have been made in both lines of endeavor to the improvement of agriculture. Particularly striking is the summary by Warburton[3] of accomplishments in extension during the decade 1914–1924, the period beginning with the inauguration of the Smith-Lever Act. The summary of the next decade ending with the current year will undoubtedly be even more impressive. In the face of this, one hesitates to criticise, but it must be remembered that progress is best made as the result of constructive criticism. With this axiom in mind and with a background of some 25 years of experience, the early part of which was in the rôle of an extension man, the writer dares to point to certain phases of the relationship between research and extension in which he sincerely believes improvement can be made.

Perhaps the discussion should be bounded by an attempt to define research and extension. Sometimes these two fields of effort are so closely integrated that it is difficult to tell where one leaves off and the other begins, although for administrative purposes the line of cleavage is sometimes clearly though not always logically drawn. Some years ago Dr. E. W. Allen[4] furnished a definition of research as compared to extension which seems helpful in this connection. His definition, which was included in a special report made for and to the New York State College of Agriculture, was as follows:

"Research is here used in a generic sense to include the various types and grades of effort for advancing knowledge, securing and verifying information, testing its application, and reducing it to

[1]Paper No. 210, Department of Plant Breeding, Cornell University, Ithaca, N. Y. Paper also read before the Northeastern Section of the American Society of Agronomy in joint session with Section O, A. A. A. S., and the Potato Association of America, December 29, 1934, Pittsburgh, Pa. Received for publication January 26, 1935.

[2]Professor of Plant Breeding.

[3]WARBURTON, C. W. Ten years of cooperative extension work under the Smith-Lever Act. U. S. D. A. Mimeograph 1596. May 8, 1924.

[4]ALLEN, E. W. Research in the State Institutions under Cornell University. Mimeograph Report. 1928.

practice under varied conditions—these and similar activities where the effort is still in the acquisitive or experimental stage, as distinguished from that of teaching or aiding persons to make application to their own conditions."

In defining research, Dr. Allen has also defined extension and in a way which shows clearly how these two fields are related and integrated with each other. Research furnishes the basis for all teaching and extension. It must always precede and keep ahead. Truth must be established before it can be extended or applied. Demands of extension can stimulate and aid in research, but extension can not or should not build higher than its foundation justifies. Disregard of this fundamental relationship is logically bound to result in a situation meriting criticism.

Granting that the relationship between extension and research as stated above is correct, it is worth our while to examine the organized development of these two fields of endeavor to see whether or not the proper balance has been maintained. Of course, each of these had their beginning in the far distant past. No one can set an arbitrary date for the first piece of research or the date when it was first applied to life problems. It is fair to presume that the Neanderthal man or even his predecessor, the Peking man, must have done research and extension of a sort, in accordance with Dr. Allen's definition. As a further illustration, we may cite the field of genetics, the newest member of the biological sciences. It is not infrequently stated that the science of genetics had its beginning about 1900 with the rediscovery of Mendel's principles of heredity. As a matter of fact, the roots of this science go back much further, and Mendel had many predecessors who made important discoveries upon which he was able to build. It remained for him to provide a method of attack by means of which he was able to interpret his own findings as well as the findings of others. Other fields of research have been built up in a similar manner. Along with discoveries of new truths, applications have been made. Indeed, many times application was made before the discovery of truth. Much plant and animal breeding was done before the science of genetics was established. Here extension may be said to have preceded research and as a result sometimes worked ineffectively, as for example in the attempt to get pure breeding stock of the Andalusian fowl, roan cattle, and the commercial carnation.

Organization of research on a comprehensive scale had its beginning in the United States in 1862 with the passage of the land-grant act for establishment of agricultural colleges. The funds provided by this act, supplemented by those provided through the passage of other acts such as the Hatch and Adams, together with appropriations by the individual states, have resulted in the establishment of agricultural research on a broad and firm basis in the United States. Some 60 years later, the Office of Experiment Stations[5] reported expenditures for the year 1924 as follows:

[5]OFFICE OF EXPERIMENT STATIONS. Work and Expenditures of the Agricultural Experiment Stations. 1924.

Funds administered by Office of Experiment Stations	$ 1,743,600
Funds in addition to above	8,594,074
Total	$10,337,674

The above figures do not include expenditures made by private research institutions not affiliated with the agricultural colleges or experiment stations. The year 1924 was chosen because it marked the end of the first 10-year period of organized extension in the United States. The more than 10 million dollars which was spent for organized research in the United States in the year 1924 seems a sizable sum and it would be superfluous to point out to a group of agronomists the great contributions made since 1862 to the improvement of agriculture. Suffice it to say that they are many in number and that their monetary value to the nation has been immeasurably greater than their cost.

For comparison let us now briefly trace the development of organized extension. This really had its beginning in the demonstration work started in the South by Dr. Seaman A. Knapp in 1904. In 1909, President Theodore Roosevelt's Country Life Commission rendered its report. This gave an impetus to the movement for an organized program of extension which finally culminated in the passage of the Smith-Lever Bill in 1914, the first of a series of acts to promote extension, some 60 years after organized research had been established. That it seems to be catching up pretty well with its foundation source is evidenced by the following items taken from the report referred to above:

Year	Expenditure	Men agents	Women agents	Boys' and girls' club agents	Extension specialists in states
1914	$ 480,000	500	200	?	?
1924	18,660,000	2,239	921	126	800

While the figures given are for 1924, it is not likely that a summary of the 10-year period ending with 1934 would show much of a change in the relative status of extension and research as evidenced by the funds expended.

It is obvious that organized extension has developed at a high rate of speed as compared with the development of organized research. This is not surprising. Successful extension efforts make an immediate appeal to the public. The public does not understand the philosophy that is involved in inbreeding field or sweet corn; the generally accepted explanation of heterosis or hybrid vigor; the reason or necessity for from 6 to 10 or more years of experimentation, but it does recognize at once, after a demonstration or two, the value of double-crossed corn. The end product makes an immediate appeal. The careful, painstaking, and scientific research of the plant pathologist does not arouse much interest in the general public. But an

application of dust or spray that will stop the ravages of a destructive disease will command interest and approval at once. Such examples could be furnished by the score.

It is well known to all of us that extension activities naturally make their appeal to the public so strongly that the latter is often led to request aid for problems faster than research can provide the facts. By his public, the extension man is supposed to be able to answer all questions and solve all problems. Herein lies a pitfall. An extension man, unless he is well trained and blessed with a good sense of balance, may be tempted to extend beyond the limits of demonstrated knowledge, in order to meet the demands of his clientele. Most of us are familiar with this type of man who answers with assurance and authority every question put up to him by the farmer. Nearly every state has one of these. He is a thorn in the flesh to the research man, because he is usually a fine personality, aggressive, has a large following, and is right a little more than half of the time. The times he misses are forgotton, his hits are long remembered, as are the predictions of the local weather prophet or the cattle breeder who attempts to control the sexes of his calves by bizarre methods.

The development of organized extension has been so rapid that it has been difficult to develop the personnel to meet the demand. This has resulted in the employment of men whose experience and training have been inadequate. They may have had good organization ability and may have been endowed with energy and personality, indeed they should be, but they lacked sufficient basic knowledge of subject matter and had neither knowledge of nor sympathy for the methods of research. It is thus easy for them to drop into the pitfall mentioned above.

The research man has been over-shadowed and out-distanced by the extension man. This may have been inevitable on account of the very nature of things, some of which were mentioned above. Particular attention has been called to some of the faults of the extension man. It is only fair to state here that the research man has some responsibility in this connection. Perhaps it should be left for the extension representative to list the defects and faults to be found in the field of research, but as evidence that we are not a smug and self-complacent group, attention should be called to the following four points which will stand scrutinizing.

First of these is the apparent lack of appreciation on the part of some research men as to what the important problems really are. It is not scientifically wrong to assume that any Truth is worthy of discovery. But in agricultural research some regard should be had for the relative economic value of the problems presented. This reasoning leads us naturally to the second criticism of the research program, which is the ignorance or forgetfulness of the real purpose of agricultural research supported by public funds. The public pays the bill and is entitled to consideration. Of course, no one can say when and where the results of research may be applied. Some times very abstruse problems have been attacked and solved, which apparently had no possible chance of application in any way, but which later were applied in a manner so as to affect mankind very materially. Some of

the earlier discoveries of organic chemistry may be cited here. The research man was merely interested in chasing the carbon atom around the benzene ring. But the gigantic dye business was later founded on the basis of his work. Nevertheless, in spite of this point of view, the research man in the agricultural college or experiment station should choose his problems with respect to the needs of the state so far as possible.

The third criticism of the research man concerns his attitude of ultra-conservatism. Just as the extension man is apt to go off "half-cocked" on some proposition, so is there the tendency for the research man to withhold application of his discovery until he has checked, double-checked, and confirmed everything, even to the "speck on the nail of the toe on the foot on the leg of the flea on the hair of the tail of the dog." A happy medium in regard to this point should be striven for. Care should be taken not to release the results of research for application before they have been substantiated. One mistake along this line will neutralize the benefits of ten successful ventures. But the investigator should be constantly on the alert to put important findings into use as promptly as possible.

The fourth criticism against the research man is the tendency he sometimes has to develop a superiority complex, to consider his work on a higher level than that of the extension worker. There is only one remedy for such persons and that is to let them go out and attempt to put across a piece of extension.

To summarize this discussion up to this point, it seems fair to state that the coordination between the extension man and the research man is not all that it should be. Probably the best explanation of this situation can be based upon the relatively rapid development of organized extension work and this rapid development is easily explained on the basis of the strong appeal to and intimate contact with the paying public which the extension enterprise has. Organized extension has reached a point after a 20-year period where it is overshadowing research and making demands which the latter is unable to meet.

The remedy for this situation does not lie in an antagonistic or destructive policy. Organized extension should not be curtailed. Rather, on the other hand, it should be expanded to meet pressing needs. Neither in these times of stress, with all the talk about overproduction and the need for a "research holiday", should it be forgotten that research is the foundation, the basis of all extension activity and that the super-structure now has possibly builded higher than its foundation justifies. The research program should not be curtailed but should be expanded to meet the pressing needs of extension. One only has to mention the present national soil erosion program to bring to mind scores of problems which must be solved by research before the findings can be extended and applied.

Another remedy lies in providing a closer relationship between extension and research men. The ideal arrangement in the opinion of the writer is to have them together in the same subject-matter department, where research men, teachers, and extension men are closely associated. Much is to be gained by this close association.

Particularly does it tend to keep the extension man up to date in the field. This acts as a balance wheel to prevent "over-extending." In turn the research worker is brought into intimate contact with problems from the outside which might have otherwise entirely escaped his attention but which are thus brought to him. This broadens and strengthens his work. In addition to this there should be close coordination and cooperation of related subject-matter departments. Very few, if any, departments of agricultural colleges of today are organized on a wide enough basis to include all the fields of knowledge necessary to the solution of problems. Thus, the plant breeder at Cornell, for example, finds it highly desirable to cooperate closely with the departments of Vegetable Crops, Agronomy, Plant Pathology, Entomology, Floriculture, and Botany. Such cooperation is as valuable to the extension worker as it is to the investigator.

It was stated above that the rapid development of organized extension had resulted in the bringing in of men with inadequate training and experience. This raises the question as to what should be the training of an extension specialist in the agricultural college. The writer believes that he should have an educational background and training equal to that of the resident teacher or investigator. He should be thoroughly grounded in the subject matter of his department. He should be familiar with the methods and results of research in his field, and if possible, he should keep his "hand in" by carrying along a piece of research. With this training and experience he would realize the limitations of research. From his contacts in the field he would bring back many problems to be investigated. This would be a stimulus to the research of the department. At times the extension man might find it desirable to do considerable educational work. Reference has already been made to the use of double-crossed corn. This may be handled by rule of thumb methods, but many farmers will not understand the reasons for these and will attempt short cuts which can only result in failure. Some have expressed the opinion that state-wide educational campaigns on the theories and principles involved in the production of double-crossed corn may be desirable. Such a campaign would challenge the best efforts of an extension man. It is obvious from the above that the training suggesgested for the extension man is the equivalent of that obtained in connection with the doctorate degree and of the same grade as that usually expected of the teacher or investigator.

Finally, the extension force of an agricultural college should not present a divided front to the public. No matter what the internal departmental organization may be, and it does vary considerably in different colleges, boundary lines should be eliminated so far as the public is concerned. Where the extension men are placed with the subject-matter departments, instead of in a central extension office, this final suggestion offers some difficulties, but these are not so great as those that are sure to arise through lack of intimate contact and association with the subject-matter department. This united front can be efficiently maintained by sustained, close cooperation between related subject-matter departments or divisions. Such cooperation is a practical necessity.

In conclusion, one can express only the greatest appreciation and respect for the accomplishments of both agricultural research and extension in the United States. Probably in no other country up to the present time have the needs of the farmer been so fully met in this regard. Such problems as have arisen and such criticism as has been made are due to a lack of a real and continuing appreciation of the fundamental relationship of these two fields of service. One is necessarily based upon the other. This fact cannot be ignored. That it has been, is due to the very nature of the work in the two fields. The work of the research man is an unknown book to the layman and will remain so, for the most part, for a long time to come. For this reason it does not make an appeal to the public. The effort of the extension man, on the other hand, is immediately appreciated by the public, which can at once see and evaluate the advantages resulting from it. This situation tends to over-shadow research activity and to set up extension work as a separate and entirely independent field. The remedy lies in the complete recognition of the fundamental relationship between the two fields. This can best be brought about by closer coordination of research and extension workers based upon subject-matter organization and by providing that the latter group be as well trained in the fundamentals of the subject as is the former group.

A COMPARISON OF GLASS AND QUINHYDRONE ELECTRODES FOR DETERMINING THE pH OF SOME IOWA SOILS: I. A COMPARISON OF DIFFERENT TYPES OF GLASS ELECTRODES[1]

Harold L. Dean and R. H. Walker[2]

DURING the past decade the quinhydrone electrode has been used extensively for determining the hydrogen-ion concentration of soils. It is considered to be well adapted to the study of reaction in soils because of its simplicity and ease of operation, and also because of its accuracy in most soils. As is well known, however, its use is restricted to soils having a reaction more acid than pH 8.0 to 8.5, and to soils containing no oxidizing or reducing substances in sufficient concentration to interfere with the normal dissociation of the quinhydrone.

In recent years a number of investigators, notably Karraker (14),[3] McGeorge (20), Baver (1), Heintze and Crowther (11), and Naftel, Schollenberger, and Bradfield (23) have noted that erroneous results were obtained where the quinhydrone electrode was used to determine the hydrogen-ion concentration of certain soils having a neutral or even an acid reaction. The presence in soils of comparatively large amounts of the higher oxides of manganese has been found to cause an error in the measurement of the hydrogen-ion concentration. Heintze and Crowther (11) attributed this error to the reduction of the higher oxides of manganese by the hydroquinone derived from the dissociation of the quinhydrone. Subsequently, the reduced manganese hydrolyzes to form manganese hydroxide which reacts with the soil acids. This explanation has been confirmed by the work of Naftel, Schollenberger, and Bradfield (23) and by that of Naftel (22).

In order to overcome the difficulties encountered in the use of quinhydrone for hydrogen-ion determinations in soils, it has been suggested that the glass electrode be used. As early as 1906, Cremer (5) found that a potential difference may be set up where two solutions are separated by a thin glass membrane, the potentials being a function of the hydrogen-ion concentration. Several investigators (2, 3, 4, 9, 12, 15, 18, 21) have found the glass electrode to give results equally as reliable as the hydrogen electrode. Furthermore, they have found the glass electrode to be as rapidly operated as the quinhydrone electrode and more widely applicable than either of the other two. Naftel, Schollenberger, and Bradfield (23) found the glass electrode to be well adapted for soil reaction measurements and also to be free from the inherent errors of commonly used methods.

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[2]Research Fellow and Research Associate Professor of Soils, respectively. The authors are indebted to Dr. P. E. Brown for suggestions and criticisms offered in the course of this work and in the preparation of the manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 435.

Many types of glass electrodes have been used in determining the hydrogen-ion concentration of soils. Probably the types most widely used are the (a) plain bulb, quinhydrone; (b) plain bulb, silver-silver chloride; (c) reëntrant, silver-silver chloride, and (d) the MacInnes-Dole type of membrane, silver-silver chloride. The composition of the glass used for glass electrodes is extremely important and much

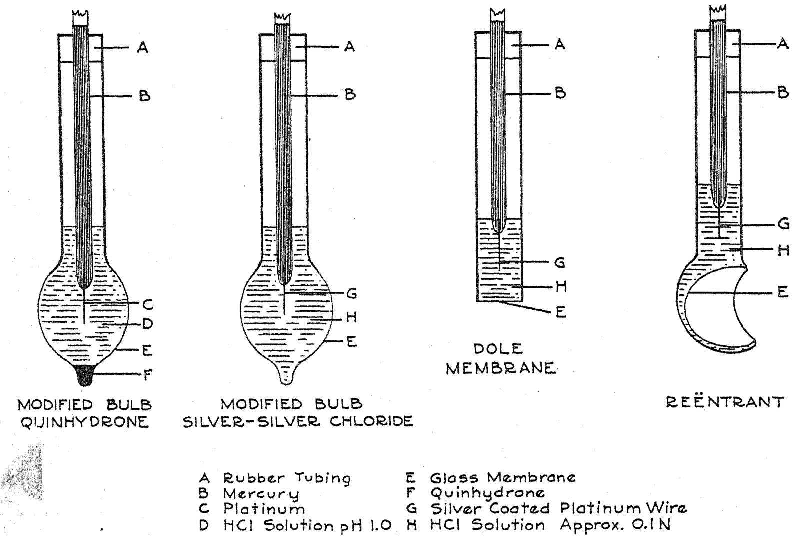

FIG. 1.—Types of glass electrode employed.

attention has been given to this by Hughes (13), MacInnes and Dole (19), Elder (7), and others. It is generally agreed that a soft glass containing approximately 72% of SiO_2, 22% of Na_2O, and 6% CaO gives the best results.

Inasmuch as the glass electrode has been found useful in other work where accurate pH measurements were desirable, and also that it has been used to a limited extent for measuring the reaction of soil, it was thought advisable to investigate further the feasibility and practicability of using it in pH determinations on soils. The initial study made in this investigation was a comparison of different types of electrodes and a study of their suitability for pH measurements in soils. The results obtained are presented in this paper.

EXPERIMENTAL PROCEDURE

In this study the adaptability of four types of glass electrodes for pH determination in soil was investigated. The types used were (a) the modified bulb, silver-silver chloride, as used by Goodhue (10); (b) the modified bulb, quinhydrone made according to the specification of the Leeds and Northrup Co.; (c) the reëntrant, silver-silver chloride, a modification of the Kerridge (16) electrode; and (d) the MacInnes-Dole (17) type of membrane, silver-silver chloride. A diagrammatic sketch of these types of electrodes is given in Fig. 1. The electrodes were made from Corning glass No. 015.

Glass electrodes have a high electrical resistance, the extent of which is from 2 to 100 megohms. It is impossible, therefore, to make measurements with the ordinary galvanometers and potentiometers commonly found in laboratories. In order to control high resistance the quadrant electrometer or the vacuum tube amplifying unit must be used. It is also essential that the apparatus be shielded and insulated from any outside interference.

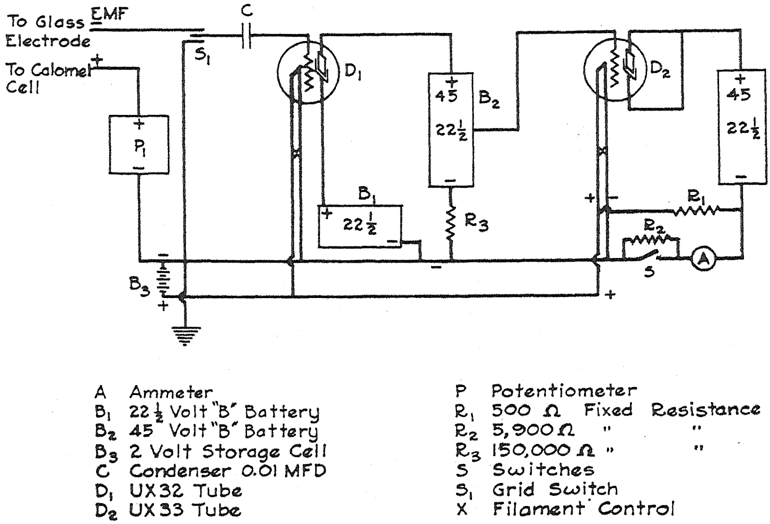

FIG. 2.—Circuit diagram of the vacuum tube amplifying unit employed in determining pH with the glass and quinhydrone electrodes.

Throughout the experiments reported here the vacuum tube circuit was used with the potentiometer. It was constructed according to Goodhue's (10) modification of Ellis and Kiehl's (8) vacuum tube circuit. The circuit diagram of this apparatus is presented in Fig. 2. With this amplifying unit it is possible to measure cells with very high resistance with an accuracy within 1 millivolt. With the glass electrode greater accuracy than this is not necessary inasmuch as each electrode is standardized against a known buffer solution.

The potentiometer used with the vacuum tube amplifying unit was a Leeds and Northrup hydrogen-ion potentiometer. A wiring diagram of the complete setup is given in Fig. 3.

It was found desirable to make pH determinations with the glass electrode under controlled conditions of temperature; hence, the electrodes were kept in a Freas electric incubator and all the determinations were made at 25°C. In order to maintain the temperature within a narrow range of fluctuation a cooling coil was installed in the incubator through which cold water could flow at a controlled rate.

Samples of five different soil types were used in the experiment, namely, Tama silt loam, Grundy silt loam, Shelby loam, Marshall silt loam, and Carrington loam. The soils were air-dried and passed through a 20-mesh sieve. A 30.0-gram sample of soil was placed in a 150-cc extraction flask and mixed with 75 cc of CO_2-free distilled water. The mixture was shaken for 1 minute and then allowed

to stand for 2 hours at which time the supernatant liquid was poured into a specially constructed "U-shaped" tube and the glass electrode introduced into the liquid. The electrode was so adjusted that the surface of the liquid inside the electrode was level with the surface of the liquid outside. Then the KCl-agar bridge making contact with the calomel half-cell was introduced and the potential measured. The voltage readings given by the electrodes were calculated to pH by the Youden and Dobroscky (24) method.

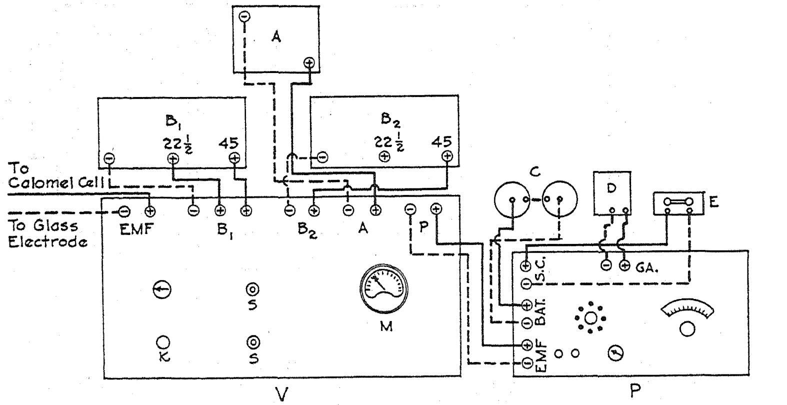

FIG. 3.—Wiring diagram of the electrometric apparatus, including the hydrogen-ion potentiometer and the vacuum tube amplifying unit employed determining pH with glass and quinhydrone electrodes.

RESULTS

In comparing the reliability of the different types of glass electrode for measuring the pH of soils, the potential of quadruplicate samples of each soil was determined by each of the four types of electrode, the electrodes being used simultaneously on each sample of soil. The results are shown in Table 1.

In the case of the Tama silt loam, the modified bulb, silver-silver chloride electrode gave a slightly higher average pH value and the reëntrant type of electrode gave a slightly lower average pH value than the other electrodes. In the case of the Carrington loam, the reëntrant type of electrode gave a slightly higher average pH value and the MacInnes-Dole membrane type gave a slightly lower average value than the other electrodes. The modified bulb, silver-silver chloride electrode gave the highest average pH value of the electrodes on Shelby loam and the modified bulb quinhydrone type the lowest average value. In the case of the Grundy silt loam, the modified bulb, quinhydrone electrode gave a higher average pH value than the other electrodes and the modified bulb and reëntrant electrodes the lowest average pH value. On the Marshall silt loam, the MacInnes-Dole

TABLE 1.—*The pH of quadruplicate samples of five soils as determined by four types of glass electrode.*

Sample No.	Types of glass electrode			
	Modified bulb Ag/AgCl	Reëntrant	Modified bulb quinhydrone	MacInnes-Dole
		Tama Silt Loam		
1	5.03	4.98	5.06	5.09
2	5.09	4.99	5.01	4.77
3	5.06	4.99	5.03	5.01
4	5.04	4.99	5.06	5.04
Average	5.06	4.99	5.04	4.98
		Carrington Loam		
1	5.08	5.13	5.09	5.06
2	5.08	5.09	5.13	5.11
3	5.06	5.06	5.01	5.06
4	5.11	5.06	5.08	5.04
Average	5.08	5.09	5.08	5.07
		Shelby Loam		
1	5.82	5.81	5.78	5.84
2	5.87	5.70	5.74	5.79
3	5.96	5.81	5.84	5.81
4	5.89	5.87	5.80	5.79
Average	5.89	5.80	5.79	5.81
		Grundy Silt Loam		
1	5.40	5.38	5.47	5.43
2	5.35	5.38	5.48	5.47
3	5.40	5.35	5.45	5.45
4	5.31	5.37	5.47	5.45
Average	5.37	5.37	5.47	5.45
		Marshall Silt Loam		
1	7.46	7.36	7.45	7.56
2	7.46	7.34	7.41	7.53
3	7.46	7.29	7.43	7.56
4	7.45	7.23	7.36	7.55
Average	7.46	7.30	7.41	7.55

membrane electrode gave the highest average pH value and the reëntrant type the lowest average value. It appears that no one type of electrode gave consistently higher or lower results on the various soils than the other electrodes.

While making the determinations on the Marshall silt loam, it appeared that the electrodes were not functioning the same as they had in the acid soils. Considerable drift occurred with all electrodes, and inasmuch as the drift in potential was rather large at times, the readings were taken at the point of apparent equilibrium. From 2 to 8 minutes elapsed from the time the electrodes were immersed in the

soil suspension until the readings were finally taken. In a later experiment it was found, however, that the potential became constant after approximately 10 to 15 minutes. The cause of the potential drift was not definitely determined.

In order to determine the extent of variation of the pH values obtained with the different electrodes, the total range of variation, the probable error of the mean, and the standard deviation of the items were calculated from the total number of pH values for each soil. These data are shown in Table 2.

TABLE 2.—*The variation in pH as determined on quadruplicate samples of each soil by four different types of glass electrodes.*

Soil type	Variation in pH	Probable error of the mean	Standard deviation
Tama silt loam	0.32	0.012	0.024
Carrington loam	0.12	0.005	0.032
Grundy silt loam	0.17	0.009	0.056
Shelby loam	0.26	0.010	0.060
Marshall silt loam	0.33	0.016	0.098

As may be noted, the total range of variation for Carrington loam was within 0.12 pH; 50% of the total number varied within 0.005 of a pH above or below the mean as indicated by the probable error and two-thirds of the total number varied within 0.032 pH above or below the mean as indicated by the standard deviation. The data secured with the other soils varied slightly more than this and were most variable in the case of the Marshall silt loam where the range of variation was 0.33 pH. Even with this soil, however, the probable error of the mean was not large, being 0.016 pH.

From the data obtained it may be concluded that all four types of glass electrode employed in this test gave similar results with the soils studied, and further, that the extent of the variations in the results obtained in any case were extremely small and well within the limits of accuracy necessary.

Inasmuch as all the electrodes gave comparable results, it was necessary to select one type of electrode for further experiments. From the standpoint of practicability in preparation and use, the modified bulb silver-silver chloride type of electrode has some advantages not possessed by the other electrodes; therefore, it was considered the most desirable for further use and study. It is stronger, more durable, and easier to construct and maintain than the other types of electrodes.

In order to have a supply of these electrodes available in the laboratory, 11 electrodes were constructed and treated with a hydrochloric acid solution of pH 1.0 for 24 hours. The potentials of the glass and quinhydrone electrodes were then determined in two buffer solutions, potassium acid phthalate and phosphate. The results are presented in Table 3.

Assuming that the quinhydrone electrode indicated the proper pH value of these buffer solutions, it may be noted that 8 of the 11 glass electrodes gave pH values within 0.02 of the proper values and that

TABLE 3.—*The pH values obtained with eleven glass electrodes constructed from one stock of glass in an unknown phosphate buffer.*

Electrode No.	Potential in millivolts		Difference in potentials	pH of unknown phosphate buffer
	Standard acid phthalate buffer	Unknown phosphate buffer		
I.........	0.1438	0.3616	0.2178	7.67
II.........	0.1451	0.3631	0.2180	7.67
III.........	0.1325	0.3501	0.2171	7.65
IV.........	0.1352	0.3542	0.2190	7.68
V.........	0.1459	0.3629	0.2170	7.65
VI.........	0.1459	0.3480	0.2021	7.40
VII.........	0.1500	0.3675	0.2175	7.67
VIII.........	0.1490	0.3649	0.2159	7.63
IX.........	0.1445	0.3623	0.2178	7.67
X.........	0.1321	0.3401	0.2080	7.50
XI.........	0.1201	0.3389	0.2188	7.68
QH.........	0.2184	0.0005	0.2179	7.67

3 electrodes failed to function properly. It is concluded from these results that when several electrodes are constructed properly from one stock of glass and tested in buffer solutions, they will, in the main, function similarly and can be depended upon, with a few exceptions, to give accurate results.

SUMMARY AND CONCLUSIONS

1. A study was made of the adaptability of the glass electrode for determining the hydrogen-ion concentration of soils.

2. A potentiometric setup suitable for use with the glass electrode was described. This included a vacuum tube amplifying unit in combination with a Leeds and Northrup hydrogen-ion potentiometer and other commonly used instruments.

3. Data are presented which show that four different types of glass electrode gave similar results when the hydrogen-ion concentration of soils was determined. The variability in pH of replicate samples of soil was extremely small with each type of electrode.

4. The modified bulb, silver-silver chloride type of electrode was found most practicable and desirable because of its ease of construction, strength, durability, and maintenance.

5. Several glass electrodes of the modified bulb type constructed from one stock of glass were found, in the main, to function similarly, and the data indicate that these electrodes may be depended upon to give accurate results.

LITERATURE CITED

1. BAVER, L. D. The drift in potential of the quinhydrone electrode. Jour. Amer. Soc. Agron., 20: 1125–1140. 1928.
2. BAYLISS, L. E., KERRIDGE, P. E., and VERNEY, R. C. The determination of the hydrogen ion concentration of the blood. Jour. Phys., 61: 448–54. 1926.
3. BEDFORD, M. H., KELLER, W. H., and GABBARD, J. L. The effect of hydrogen-ion concentration on the flocculation values of chromic and aluminum oxide soils. Jour. Amer. Chem. Soc., 55: 3953–3956. 1933.

4. BROWN, W. E. L. The measurement of hydrogen ion concentration with glass electrodes. Jour. Sci. Instr., 2: 12–17. 1924.
5. CREMER, M. Über die Ursache der elektromotorischen Eigenschaften der Gewebe, zugleich ein Beitrag zur Lehre von den polyphasischen Elektrolytketten. Zeit. f. Biol., 47: 560–608. 1906.
6. DOLE, MALCOLM. The theory of the glass electrode. Jour. Amer. Chem. Soc., 53: 4260–4280. 1931.
7. ELDER, L. W. pH measurements with the glass electrode and vacuum tube potentiometer. Jour. Amer. Chem. Soc., 51: 3266–3272. 1929.
8. ELLIS, S. B. and KIEHL, S. J. A practical vacuum tube circuit for the measurement of electromotive force. Rev. Sci. Instr. 4: 131–137. 1933.
9. FOSBINDER, R. J., and SCHOONOVER, J. An improved method of measuring glass electrode potentials. Jour. Biol. Chem., 88: 605–614. 1930.
10. GOODHUE, L. E. Personal communication. Chem. Dept., Iowa State College, Ames, Iowa. 1934.
11. HEINTZE, S. G., and CROWTHER, E. M. An error in soil reaction determinations by quinhydrone method. Trans. Sec. Comm. Int. Soc. Soil Sci., A: 102–110. 1929.
12. HILL, S. E. The validity of the glass electrode in ammonium chloride buffer. Jour. Gen. Physiol., 12: 813–819. 1929.
13. HUGHES, W. S. Potential difference between glass and electrolytes in contact with the glass. Jour. Amer. Chem. Soc., 44: 2860–2867. 1922.
14. KARRAKER, P. E. The inaccuracy of the quinhydrone electrode in many Kentucky soils. Jour. Amer. Soc. Agron., 22: 171–180. 1930.
15. KERRIDGE, P. M. T. The use of the glass electrode in biochemistry. Jour. Biochem., 19: 611–617. 1925.
16. ————. The use of glass electrodes. Jour. Sci. Instr., 3: 404–409. 1926.
17. MACINNES, D. A., and DOLE, M. Tests of a new type of glass electrode. Ind. Eng. Chem., Anal. Ed., 1: 57–59. 1929.
18. ————, ————. A glass electrode apparatus for measuring the pH values of very small volumes of solution. Jour. Gen. Physiol., 12: 805–811. 1929.
19. ————, ————. The behavior of glass electrodes of different compositions. Jour. Amer. Chem. Soc., 52: 29–36. 1930.
20. MCGEORGE, W. T. Influence of manganiferous soils on the accuracy of the quinhydrone electrode. Soil Science, 27: 83–88. 1929.
21. MIRSKY, A. E., and ANSON, M. L. A description of the glass electrode and its use in measuring hydrogen-ion concentration. Jour. Biol. Chem., 81: 581–587. 1929.
22. NAFTEL, JAMES A. The glass electrode and its application in soil acidity determinations. Soil Res., 4: 41–50. 1934.
23. ————, SCHOLLENBERGER, C. J., and BRADFIELD, RICHARD. A study of the methods for determining soil reaction using the glass electrode. Soil Res., 3: 222–246. 1933.
24. YOUDEN, W. G., and DOBROSCKY, J. D. A capillary glass electrode. Cont. Boyce-Thompson Inst. Plant Res., 3: 347–362. 1931.

CONVERSION OF SOIL POTASH FROM THE NON-REPLACEABLE TO THE REPLACEABLE FORM[1]

F. A. E. Abel and O. C. Magistad[2]

PINEAPPLE plants in Hawaii often contain at maturity more potash per acre than was present in replaceable form in the surface acre foot of soil. Thus, Horner (7)[3] found that 9,600 mature pineapple plants grown on a plat receiving no fertilizer application contained 1,672 pounds of K_2O per acre. Soil from the same field on which these plants grew contained 1,036 pounds of replaceable potash per acre foot. In this experiment the root systems of the pineapple plants only occasionally penetrated to a depth greater than 12 inches, and it appears very unlikely that any appreciable feeding occurred in the second foot of soil. These facts strongly suggest that considerable potash must become available to the plant from non-replaceable sources during the 2 years that the plant gains maturity. This paper presents data from two experiments showing to what extent this conversion takes place. Throughout this paper replaceable or exchangeable potassium is considered synonymous with available potassium. Water-soluble potassium is included with the replaceable form.

REVIEW OF LITERATURE

In 1910, Hopkins (6) stated that the equivalent of 0.25% of the total potassium in the surface soil could be made available during one season by practical field methods. He based this statement on a study of the results of successive crop yields and their analyses.

In 1918, Plummer (11) grew oats, rye, soybeans, and cowpeas on limed and unlimed potash-deficient soil to which potassium-containing minerals were added. Plant growth was better with some minerals than with others, and on the limed soils legumes grew better than nonlegumes. Plummer believed that legumes on limed soils had bigger root systems which enabled the plant to obtain more potash; and that lime had no effect on potash solubility.

Breazeale and Magistad (2) in 1928 demonstrated that potash in the mineral form could be converted to the replaceable form. They digested pure, finely ground orthoclase powder in alkaline solutions and obtained a marked production of replaceable potassium.

More recently, Martin (9), Fraps (3), Gedroix (4), and Hoagland and Martin (5) have shown by means of pot experiments that crops obtained some potassium from non-replaceable sources, or at least that the amount of potassium in the crops exceeded the decrease of replaceable potassium in the soil.

That the conversion of potassium from the replaceable to non-replaceable form, and *vice versa*, is highly probable, was shown by Bartholomew and Jans en in 1931 (1) while working with Arkansas soils. Heavy potash fertilization shifted the

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[3]Figures in parenthesis refer to "Literature Cited," p. 444.

equilibrium toward the non-replaceable form, causing some of the added water-soluble potassium to be fixed in a non-exchangeable manner.

Volk (13) made a thorough study of potash fixation and found that some soils fix a large share of the water-soluble potash applied to them in the form of the mineral muscovite.

EXPERIMENTAL

Two experiments were conducted and will be described separately.

EXPERIMENT I

Soils.—Two typical pineapple soils were used. These are described below:

Soil No.	Location	pH value	Total K_2O %	Replaceable K_2O in M.E. per 100 grams	Remarks
917	Fd. 85, Brodie, Oahu	6.27	1.56	1.27	Fertile
923	Fd. 74, Oahu	4.57	0.36	0.04	Less productive

Containers.—Four 20-inch galvanized iron wash tubs were used as containers. A short length of copper tubing was soldered to the center of the bottom of each as a drain. The containers were painted with Ebonol paint to prevent contact of the metal with the soil. One tub of each soil was limed at the rate of 9 tons of $CaCO_3$ per acre foot of 2,400,000 pounds while another was left unlimed. Each tub contained approximately 15 kilos dry soil.

Crop.—Soybeans were first used as a crop because of their capacity to remove potash rapidly. Fifty sprouted beans were planted in each tub per crop. These beans were inoculated with the soybean group of nodule-forming bacteria to provide the plants with adequate nitrogen. Five consecutive crops of soybeans were grown, harvested, and analyzed. After the fifth crop soybeans failed to grow well and other plants, such as rice, sudan grass, and sorghum were tried. In all nine crops were grown. In three tubs the last seeding produced no growth.

Fertilization.—No fertilizer was added until after the second crop when superphosphate containing 21.4% P_2O_5 was applied at the rate of 1,050 pounds per acre foot of 2,400,000 pounds and was thoroughly incorporated in the soil. After the fourth and sixth crops ammonium sulfate equivalent to 200 pounds of nitrogen per acre foot was added.

Analyses.—The content of replaceable potash in the soils at the beginning of the experiment was determined and likewise after each crop had been harvested. The leachates were analyzed for potassium as were also samples of seeds used for each crop. At each harvest the entire plant, roots included, was carefully removed from the soil, weighed, and analyzed for potassium content. Analyses for potassium were made by the cobalti-nitrite method as modified by Truog and Volk (12).

The dry weights of the plants, weight of potash removed by the plants, and potash found in the leachates are shown in Table 1. The weight of potash removed by the plants is the total potash found in the plants minus the potash content in the seeds.

TABLE 1.—*Dry weight per crop, weight of potash (K_2O) removed by plants, and weight of potash in leachate, all values in grams per tub.*

Plant	Soil No. 917					
	Limed			Unlimed		
	Dry weight	Potash removed by		Dry weight	Potash removed by	
		Plants	Leachate		Plants	Leachate
Soybeans......	17	0.095	——	17	0.068	0.207
Soybeans......	55	0.461	0.200	52	1.045	——
Soybeans......	102	1.400	——	86	1.161	0.006
Soybeans......	55	0.825	0.005	59	0.620	——
Soybeans......	33	0.470	——	20	0.270	——
Rice..........	47	1.438	——	39	0.242	——
Sudan grass....	23	0.841	0.005	185	1.058	0.006
Sorghum......	52	0.546	0.024	31	0.309	——
Sorghum......	122	1.301	0.025	0	0.0	0.010
Total.......	506	7.377	0.259	489	4.773	0.229

Plant	Soil No. 923					
	Limed			Unlimed		
	Dry weight	Potash removed by		Dry weight	Potash removed by	
		Plants	Leachate		Plants	Leachate
Soybeans......	30	0.083	——	14	0.257	——
Soybeans......	70	0.506	0.011	50	0.305	0.126
Soybeans......	108	0.357	——	43	0.400	——
Soybeans......	50	0.020	——	8	0.130	0.017
Soybeans......	21	0.063	——	9	0.112	——
Rice..........	42	1.081	——	4	0.155	——
Sudan grass....	56	0.100	0.009	20	0.120	0.038
Sorghum......	11	0.045	——	8	0.062	——
Sorghum......	0	0.0	0.033	0	——	0.149
Total.......	388	2.255	0.053	156	1.542	0.330

The displaced soil solution of soil No. 917 contained 15 p. p. m. of potash which was 2½ times as great as that of soil No. 923. A ratio of this type was expected judging from the levels of replaceable potassium in these soils. (See description of soils.)

Twenty-five months elapsed between planting the first crop, March 3, 1931 and harvesting the ninth crop, April 28, 1933. It will be seen from Table 2 that during this time potassium was released from non-replaceable sources in all soils, but that the quantity released was greater in the limed soils than in the unlimed.

It would appear that lime increases the rate at which non-replaceable potash becomes available, but Plummer (11) in his experiment suggests that the increased root area resulting from increased growth in the presence of lime may be a more correct explanation.

TABLE 2.—*Summary of data to show the amount of replaceable potash released from non-replaceable sources.*

	Soil No. 917		Soil No. 923	
	Limed	Unlimed	Limed	Unlimed
Soil content replaceable K_2O, grams:				
Beginning of experiment	6.075	6.075	2.989	2.989
End of experiment	2.002	1.308	1.364	1.199
K_2O removed, grams:				
By plants	7.377	4.773	2.255	1.541
In leachate	0.259	0.229	0.053	0.330
Total removed	7.636	5.002	2.308	1.871
Grams potash released:	3.563	0.235	0.683	0.081
Amount released in % of replaceable at beginning	259.8	6.6	15.5	1.8
Pounds K_2O released per acre foot annually (calculated)	58.6	3.9	23.9	2.7

In order to obtain further information, a new experiment was planned using nonleguminous plants. This is described below.

EXPERIMENT II

In this second experiment on the ability of soils to replenish the store of available potash, non leguminous crops were grown on six soils. The experiment occupied a period of 20 months, from August 31, 1932 to May 10, 1934.

Soils.—Six soils from four islands representing the major pineapple sections were used. They varied from one extreme to the other with respect to their supply of replaceable potassium. The percentage base saturation, given in the last column of Table 4, was obtained as the quotient of milligram-equivalents $\frac{(Ca+Mg+K_2O)\ 100}{\text{Total}}$.

A description and analyses of these soils is given in Tables 3 and 4.

TABLE 3.—*Location of soils used in Experiment 2.*

Lab. No.	Island	Section and field
621	Lanai	Fd. L-1
866	Maui	Honolua, Fd. 104
2204	Oahu	Pearl City, Fd. 80
2519	Kauai	Kauai Pineapple Co., Fd. 22D
5027	Kauai	Hanalei, Fd. 2
5028	Oahu	Kunia, Fd. 80

In Table 4 replaceable hydrogen to pH 7.0 is given. It was determined by adding increments of known quantities of barium hydroxide to the soil in solution and shaking well at intervals for 1 week. At this time pH values were determined, using hydrogen electrode, and the values for pH were plotted against amounts of barium hydroxide added. The quantity of replaceable hydrogen to pH 7.0 could then be read from the curve connecting the plotted points.

TABLE 4.—*The replaceable base status of soils used in Experiment 2, with determinations made at the conclusion of the experiment and results expressed in milligram-equivalents per 100 grams of soil.*

Lab. No.	Treatment	H	Ca	Mg	K_2O	Total	Per cent saturated	pH
				Cropped Soils				
621	Limed	None	20.06	1.01	0.31	21.38	100	7.40
621	Unlimed	0.78	16.06	1.20	0.28	18.32	96	6.91
866	Limed	0.83	11.68	0.65	0.07	13.23	92	6.58
866	Unlimed	2.06	5.77	0.94	0.10	8.87	77	6.18
2204	Limed	2.12	6.97	0.26	0.07	9.42	78	6.21
2204	Unlimed	5.05	2.60	0.31	0.10	8.06	37	4.95
2519	Limed	2.61	6.17	0.24	0.07	9.09	71	6.01
2519	Unlimed	3.93	2.84	0.28	0.03	7.08	44	5.08
5027	Limed	1.84	8.68	0.27	0.06	10.85	83	5.78
5027	Unlimed	4.42	3.55	0.29	0.06	8.32	47	5.26
5028	Limed	10.61	8.09	0.21	0.10	19.01	44	5.37
5028	Unlimed	8.84	3.40	0.36	0.08	12.68	30	4.99
				Fallow Soils				
621	Limed	None	20.32	0.96	1.32	22.60	100	7.50
621	Unlimed	1.35	14.92	0.90	1.22	18.39	93	6.56
866	Limed	1.61	11.22	0.61	0.60	14.04	89	6.42
866	Unlimed	2.25	4.88	0.69	0.59	8.41	73	5.12
2204	Limed	2.47	6.96	0.16	0.41	10.00	75	5.65
2204	Unlimed	4.21	2.91	0.20	0.40	7.72	45	4.38
2519	Limed	2.39	6.20	0.07	0.17	8.83	73	5.59
2519	Unlimed	4.79	1.78	0.23	0.21	7.01	32	4.68
5027	Limed	2.23	7.68	0.26	0.16	10.28	88	5.80
5027	Unlimed	5.60	2.95	0.27	0.13	8.95	37	4.75
5028	Limed	11.08	7.28	0.17	0.24	18.77	41	5.41
5028	Unlimed	15.92	2.22	0.21	0.22	18.57	14	4.71

The very low degree of base saturation of some soils, as indicated in Table 4, suggests that these might be unproductive. While soil No. 5027 is marginal with respect to pineapples, soil No. 5028 is classed as a moderately productive one for this crop.

Containers.—Mitscherlich pots (10) were used for containers. For each soil there were six pots, three limed and three unlimed. Of these, two limed and two unlimed were planted. The remaining limed and unlimed pots were kept fallow. The soils of fallow pots were exposed to the sun and rain.

Crop.—Sorghum was used as a crop. It was expected to remove potash rapidly and to grow well in these soils. A total of five crops was harvested, weighed, and analyzed as described in Experiment I.

Fertilization.—In order to obtain large yields it was necessary to supply nitrogen and phosphate by fertilization. Four applications of nitrogen were made, one for each crop after the first, at the rate of 100 pounds nitrogen per acre foot of soil. Only one application of superphosphate at the rate of 500 pounds of P_2O_5 per acre foot was made. This occurred while growing the first crop. The nitrogen was applied as ammonium sulfate and as ammonium nitrate.

Analyses.—The replaceable potash content of the soils at the beginning of the experiment was determined, and after removal of the

last crop the same soils were analyzed for replaceable potassium, hydrogen, calcium, and magnesium. The potash content of all crops, seed samples, and leachates was determined and the sum of potash removed by the crops and in the leachates. The cobalti-nitrite method (12) was used for all potash determinations. Standard base replacement methods were used for the other elements. Crop yields and crop and soil analyses are given in Tables 5 and 6.

TABLE 5.—*Dry weights of crops grown in grams per pot.*

Soil No.	Limed		Unlimed	
	Total weight of crops	Av. weight of crop per pot	Total weight of crops	Av. weight of crop per pot
621	220		278	
621	273	247	249	264
866	330		245	
866	278	304	268	257
2204	245		147	
2204	242	244	166	156
2519	247		228	
2519	235	241	269	249
5027	238		225	
5027	248	243	229	227
5028	189		146	
5028	204	197	154	150
Total crop yield	2,949		2,604	

DISCUSSION

Turning to Table 5, we note that the yield per pot for five cuttings of sorghum varied from 189 to 330 grams on the limed soils and from 146 to 278 grams on the unlimed. The total yield on limed soils was 2,949 grams compared with 2,604 grams on the unlimed. Thus, we see that the better yield on limed soils was not restricted to legume crops.

The data bearing on quantities of potassium taken up by plants and liberated from the non-replaceable complex are shown as averages of two pots per treatment in Table 6.

The amount of potash removed in the crop in case of soil No. 621 bears a large ratio to the total amount of replaceable potash originally present. With potash-deficient soils, such as No. 5028, the amount removed by the crop exceeded the original quantity of replaceable potash. The quantity of replaceable potassium in the soil about a month after the completion of the test is shown in column 3, and this amount in some instances exceeds the original value. Of great interest are the values given in the last three columns showing the quantity of potassium which has been converted from a non-replaceable to a

TABLE 6.—*Amount of replaceable potash released from non-replaceable sources.*

Soil No.*	Soil content replaceable K_2O, grams		K_2O removed, grams			Grams K_2O released	Amount released in per cent replaceable at beginning	Lbs. K_2O released per acre foot annually (calculated)
	Beginning	End	By plant	Leachate	Total			
			Cropped Soils					
621-L	1.712	0.504	1.443	0.019	1.462	0.254	15	91
621-U	1.712	0.529	1.203	0.021	1.224	0.042	2	15
866-L	0.785	0.136	0.827	0.006	0.833	0.184	23	66
866-U	0.785	0.188	0.646	0.007	0.653	0.056	7	20
2204-L	0.163	0.132	0.476	0.005	0.481	0.450	276	162
2204-U	0.163	0.183	0.407	0.005	0.412	0.432	265	155
2519-L	0.182	0.141	0.324	0.013	0.337	0.296	158	105
2519-U	0.182	0.064	0.300	0.023	0.323	0.205	112	73
5027-L	0.059	0.089	0.210	0.009	0.219	0.249	421	93
5027-U	0.059	0.108	0.167	0.004	0.171	0.220	372	79
5028-L	0.092	0.196	0.238	0.009	0.247	0.351	383	127
5028-U	0.092	0.150	0.233	0.011	0.244	0.302	328	109
			Fallow Soils					
621-L	1.712	2.480	——	0.064	0.064	0.832	49	299
621-U	1.712	2.296	——	0.069	0.069	0.653	38	234
866-L	0.785	1.136	——	0.055	0.055	0.406	52	146
866-U	0.785	1.108	——	0.046	0.046	0.369	47	133
2204-L	0.163	0.774	——	0.025	0.025	0.636	390	211
2204-U	0.163	0.752	——	0.049	0.049	0.638	391	229
2519-L	0.182	0.322	——	0.049	0.049	0.189	104	68
2519-U	0.182	0.402	——	0.045	0.045	0.265	145	95
5027-L	0.059	0.304	——	0.019	0.019	0.264	447	95
5027-U	0.059	0.236	——	0.012	0.012	0.189	320	68
5028-L	0.092	0.454	——	0.042	0.042	0.404	439	145
5028-U	0.092	0.408	——	0.052	0.052	0.368	400	133

L = Limed.
U = Unlimed.

replaceable form. Adding the values in the last column, a mean release of 107 pounds of K_2O per acre foot per year for six limed soils is obtained as compared with 75 pounds of K_2O for the same six soils when unlimed. In Experiment I, Table 2, the potash release was equal to 15.5 and 259.8 pounds K_2O per acre foot annually on the two limed soils, and on the same soils unlimed, 1.8 and 6.6 pounds, respectively. These values are of the same order as those reported by Hoagland and Martin (5) and by Fraps (3).

Jenny and Shade (8) have recently reviewed the conflicting literature on the effect of lime on potassium availability. In their experiment free calcium was able to replace potassium, but the study did not include conversion of potash from non-replaceable to available forms.

It was believed that an equilibrium existed between potassium in the non-replaceable and the replaceable form in the fallow soils. If no losses of replaceable potash occurred, little or no potash was expected to be converted from the non-replaceable to the replaceable state. In fact, Volk (13) indicates that under conditions of alternate wetting or drying such as these fallow soils were subject to, the po-

tassium is apt to become fixed. It was surprising, therefore, to find that in these fallow soils the amounts of potassium released from non-replaceable form were greater than in the cropped pots. (See column 9, Table 6.)

In these fallow pots, as well as in the cropped pots, potash release was greater in the limed soils. Clearly here the rate of release has no relation to root surface. The authors suggest that under conditions of alternate wetting and drying, such as occurred with the fallow pots, the following process takes place: During wetting some potash goes into solution from non-replaceable sources. On drying, the concentration of potash in the soil solution increases, some goes into the replaceable complex, and the next time the soil is wetted this does not all go back into the soil solution. Furthermore, with alternate wetting and drying under alkaline conditions base exchange material can be formed.

A study of Table 4 reveals the fact that without exception the limed soils have greater total exchange capacities than the unlimed. This can be explained on the assumption that additional base exchange material has been produced under the less acid conditions.

An attempt was made without success to analyze the effect of various factors, such as percentage base saturation and the level of replaceable potash, on rate of potash conversion from non-replaceable sources. It appears that cropping has little effect and that conditions for alternate wetting and baking are more effective in accelerating this process.

SUMMARY

Two experiments were conducted in the greenhouse using eight pineapple soils all derived from basaltic lavas. In the first experiment successive crops of soybeans were grown on two soils, one well supplied and one deficient in replaceable potassium, each with and without lime. The soils in this experiment received no potassium as fertilizer but did receive nitrogen and phosphorus. A balance sheet of readily available potash was kept.

In a second experiment similar to the first, six diverse soils were used, and two pots of each soil, limed and unlimed, were cropped with sorghum. One set of each soil remained fallow.

The conclusions were that about 100 pounds of K_2O per acre foot was made available from non-replaceable sources annually in the case of limed soils and about 75 pounds in the case of natural acid soils. The results were of the same order in the case of fallow soils, and with soils cropped with legumes on the one hand and nonlegumes on the other.

Soils having a very low amount of replaceable potash at the beginning of the test were able to release potash from non-replaceable sources as readily as soils rich in replaceable potash.

LITERATURE CITED

1. BARTHOLOMEW, R. P., and JANSSEN, GEORGE. The rate of absorption of potassium by plants and its possible effect upon the amount of potassium remaining in soils from application of potassium fertilizers. Ark. Agr. Sta. Bul. 265. 1931.

2. BREAZEALE, J. F., and MAGISTAD, O. C. Base exchange in orthoclase. Ariz. Agr. Exp. Sta. Tech. Bul. 24. 1928.
3. FRAPS, G. S. Relation of the water-soluble potash, the replaceable, and acid-soluble potash to the potash removed by crops in pot experiments. Tex. Agr. Exp. Sta. Bul. 391. 1929.
4. GEDROIX, K. K Exchangeable cations of the soil and the plant: I. Relation of plant to certain cations fully saturating the soil exchange capacity. Soil Science, 32: 51–63. 1931.
5. HOAGLAND, D. R., and MARTIN, J. G. Absorption of potassium by plants in relation to replaceable, non-replaceable, and soil solution potassium. Soil Science, 36: 1–33. 1933.
6. HOPKINS, CYRIL A. Soil Fertility and Permanent Agriculture. New York: Ginn & Co. 1910. (Pages 107–108.)
7. HORNER, J. M. A study of the composition of pineapple plants at various stages of growth as influenced by different types of fertilization. Univ. Hawaii, Pineapple Exp. Sta. Bul. 13. 1930.
8. JENNY, HANS, and SHADE, E. R. The potassium-lime problem in soils. Jour. Amer. Soc. Agron. 26: 162–170. 1934.
9. MARTIN, J. C. Effect of crop growth on the replaceable bases in some California soils. Soil. Science, 27: 123–136. 1929.
10. MITSCHERLICH, E. A. Die Bestimmung des Düngerbedürfnisses des Bodens. Berlin: Paul Parey. Ed. 3. 1930.
11. PLUMMER, J. K. Availability of potash in some common soil forming minerals—effect of lime upon potash absorption by different crops. Jour. Agr. Res., 14: 297–317. 1918.
12. TRUOG, E., and VOLK, N. J. A rapid chemical method for determining the readily available potash of soils. Jour. Amer. Soc. Agron., 26: 537–546. 1934.
13. VOLK, N. J. The fixation of potash in difficultly available form in soils. Soil Science, 37: 267–287. 1934.

DECOMPOSITION OF THE BASE-EXCHANGE COMPOUNDS OF SOILS BY ACIDS AND ITS RELATION TO THE QUANTITY OF ALUMINA AND SILICA DISSOLVED[1]

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THE base-exchange properties of soils are generally believed to be in the colloidal complex, and due both to clay and to organic matter. Mattson (13)[3] found the base-exchange capacity of colloidal clay to range from 0.164 to 1.102 M. E. per gram and the exchange capacity of humus to range from about 2.5 to 4.5 M. E. per gram, while McGeorge (12) reports the exchange capacity of ligno-humates to go as high as 4.20 M. E. per gram. Robinson (15, p. 110) found a fairly good agreement to occur with 13 soils and poor agreement to occur with 4 soils between the base-exchange capacity as estimated and that calculated by the equation $T = 0.57K + 4.55C$, in which T is the exchange capacity, K the clay content, and C the total carbon.

The base-exchange properties of clay are believed to be due to salts of one or more complex alumino-silicic acids. Any treatment which tended to destroy the base-exchange capacity of the clay might be reflected in the quantities of alumina and silica brought into solution by the treatment. The objects of the work here reported were to ascertain, first, the relation between the total base-exchange capacity and the iron and aluminum oxides dissolved from soils, and, second, the relation between the loss in exchange capacity and the materials dissolved by different strengths of acid alone and followed by 0.5 N sodium hydroxide. The information secured throws some light upon the nature of the base-exchange complex.

RELATION OF TOTAL EXCHANGE CAPACITY TO QUANTITY OF IRON AND ALUMINUM OXIDES SOLUBLE IN STRONG HYDROCHLORIC ACID

The relation between the total base-exchange capacity and the quantity of iron and aluminum oxides soluble in hydrochloric acid of 1.115 sp. gr. was determined. The total exchange capacity was ascertained by leaching with neutral normal ammonium acetate, washing out the excess ammonium acetate, and determining the absorbed ammonia by distillation with magnesium oxide. The total exchange capacity is expressed as M. E. per 100 grams of soil. The quantity of soluble iron and aluminum oxide was determined in the filtrate from 10 grams of soil digested in 100 cc of 1.115 sp. gr. hydrochloric acid for 10 hours in a boiling water bath. The percentages of the combined oxides of iron and aluminum soluble by this treatment of 259 soils were compared with the total exchange capacity.

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Texas. Received for publication March 22, 1935.

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[3]Figures in parenthesis refer to "Literature Cited", p. 454.

Of 92 soils with less than 10 M. E. exchange capacity, 59 contained less than 3% iron and aluminum oxides soluble in the acid used, and 86 contained less than 6%. Of 29 soils with more than 40 M. E. exchange capacity, none contained less than 9% of soluble iron and aluminum oxides and 25 contained more than 12%. The correlation coefficient was + .878 ± .010, indicating a very close association between the exchange capacity and the content of soluble iron and aluminum oxides.

DECOMPOSITION OF THE EXCHANGE COMPLEX BY VARIOUS STRENGTHS OF ACID AND RELATION OF THE EXCHANGE CAPACITY TO MATERIAL DISSOLVED

The exchange complex of the soil has already been shown to be very little affected by treatment for a short time with 0.2 N hydrochloric acid at room temperature (6, p. 37). It seemed desirable to ascertain the effects of different strengths of acid upon the exchange capacity and to study further the relation between the exchange capacity and the materials dissolved. For this purpose about 12 soils were selected of various origins and high in base-exchange capacity. Ten-gram portions were digested 10 hours in a boiling water bath with 100 cc of hydrochloric acid of 0.2, 1.0, 1.75, 3.5, 7.0, and 8.75 normality. With 0.2 N acid sufficient additional acid was used to allow for the basicity of the soil. After digestion, the residue was filtered off and washed. The exchange capacity of the residue was determined by the ammonium acetate method. Silica and iron and aluminum oxides were determined gravimetrically in the filtrates. Iron was determined by reduction with zinc and titration with potassium permanganate. Aluminum oxide (with some titanium oxide) was estimated by subtracting the ferric oxide from the combined iron and aluminum oxides.

The reduction in exchange capacities of the soils caused by the treatment with acid are given in Table 1. It is seen from the table that digestion with the hot 0.2 N hydrochloric acid destroyed comparatively small portions of the exchange capacity, the average for the 12 soils being 17%. The decomposition, however, was higher than that due to unheated 0.2 N hydrochloric acid. The 1.0 N acid destroyed about half of the exchange capacity. With acid of 1.75 N, 3.5 N, 7.0 N, and 8.75 N, the average percentages of exchange capacity destroyed were 63, 74, 80, and 80, respectively. There was a comparatively rapid increase in destruction of the exchange capacity with increase in the strength of the acid until about 20% of the exchange capacity remained, after which a considerable increase in the strength of the acid caused no further destruction.

The base-exchange capacities of the residues from the same treatment varied with different soils. With dilute acid, especially, individual soils differed considerably. For example, 64% of the exchange capacity of soil No. 29438 was left after treatment with 0.2 N acid, while 96% of that of No. 23950 was left after the same treatment. Considerable differences between the percentages left in different soils also occurred with the 1.0 N acid (46 to 66%), the 1.75 N acid

TABLE 1.—*Reduction of exchange capacity of soils by digestion with hydrochloric acid.*

Laboratory No.	Soil	Original exchange capacity M.E.	Exchange capacity of residue as per cent of capacity of original soil					
			0.2N	1.0N	1.75N	3.50N	7.0N	8.75N
25887....	Victoria clay loam	19.3	17	49	63	66	72	74
31321....	Amarillo silty clay loam	20.2	19	46	60	72	77	77
29438....	Lufkin fine sandy loam	23.9	36	41	53	73	84	86
31327....	Randall clay	27.6	14	34	65	74	81	81
29427....	Crockett clay loam	28.9	19	53	53	64	73	75
23950....	Frio clay	31.5	4	38	58	76	80	78
23952....	Houston clay	34.7	12	40	61	76	83	85
26089....	Catalpa clay	35.1	16	47	58	71	78	78
23946....	Miller clay	36.0	7	37	63	77	77	75
26085....	Houston clay	40.0	11	54	70	76	82	83
26823....	Lake Charles clay	45.2	21	56	68	73	78	80
26079....	Bell clay	46.4	23	53	76	80	85	86
Averages			17	47	64	74	80	80

(24 to 47%), and the 3.5 N acid (20 to 36%), but the order of the soils is not the same as with the 0.2 N acid. With the 7.0 N and 8.75 N acids, however, the variation was somewhat less, being from 15 to 28% with the 7.0 N acid and 14 to 26% with the 8.75 N acid.

From Table 2 it is seen that a high degree of relationship between the percentages of alumina dissolved and the decrease in the exchange capacity occurs with all strengths of acid for all the soils. If the quantity of alumina brought into solution by the strongest acid, 8.75 N, be given a comparative value of 100, the average relative values for the quantities dissolved by the other strengths, except 7.0 N where the value is approximately the same as for 8.75 N, are in approximately the same ratio as the figures for the relative destruction of the exchange capacity by the acid treatments.

If, instead of 100, the alumina in solution with 8.75 N acid be given a comparative value of 80, the same as the percentage of destruction of the total exchange complex by that acid, the relation between the quantities of alumina in solution and the exchange complex destroyed are comparatively close, except with the first two acids, 0.2 N and 1.0 N, where the relative destruction of exchange complex is nearly double that of the solution of alumina. The correlation coefficient between the loss of exchange capacity and the quantity of alumina brought into solution by the various strengths of acid was $+ .859 \pm .029$, showing a very high relation.

The relation between the decrease in total exchange capacity and the quantity of alumina in solution is shown more clearly when the decrease in M. E. of exchange capacity is expressed as percentages

TABLE 2.—*Percentage of alumina dissolved by acids of different strengths.*

Laboratory No.	Strength of acid					
	0.2N	1.0N	1.75N	3.50N	7.0N	8.75N
25887	0.91	1.94	3.57	4.22	5.27	4.83
31321	1.03	2.61	5.32	6.43	6.87	6.89
29438	0.59	1.91	3.51	5.17	5.23	5.95
31327	1.06	3.37	6.08	8.21	8.74	8.15
29427	0.56	3.78	4.37	6.57	7.65	7.46
23950	1.33	1.35	4.29	6.28	7.95	7.84
23952	1.21	2.44	5.21	7.36	7.82	7.58
26089	0.95	2.52	5.60	9.05	9.94	9.36
23946	1.10	3.03	7.21	10.01	11.53	11.05
26085	1.03	3.24	7.24	7.89	7.89	8.22
26823	1.09	3.67	7.90	7.71	8.68	8.04
26079	1.16	4.11	7.49	9.23	9.84	9.56
Average	1.00	2.73	5.65	7.35	8.12	7.74
Relative quantity, 8.75N = 100	13	37	73	95	105	100
Relative quantity, 8.75N = 80	10	30	58	76	84	80
Relative decrease of exchange capacity	17	47	64	74	80	80

of the alumina dissolved, also in M. E., 6 M. E. being assumed for a milligram molecule of alumina. These data are given in detail in Table 3. The percentages for the individual soils vary widely from the average with the 0.2 N and 1.0 N acids, but are reasonably close to the average with the stronger acids. The average percentage decreases from 10.02 to 5.54 as the strength of the acid increases. If

TABLE 3.—*Decrease in M.E. of exchange capacity in percentage of M.E. of soluble alumina.*

Laboratory No.	Strength of acid					
	0.2N	1.0N	1.75N	3.50N	7.0N	8.75N
25887	6.32	8.37	5.74	5.14	4.50	5.02
31321	6.41	6.10	3.85	3.82	3.82	3.78
29438	24.80	8.75	6.06	5.68	6.42	5.78
31327	6.18	4.75	4.95	4.14	4.24	4.54
29427	13.50	6.90	5.89	4.70	4.63	4.86
23950	1.67	15.20	7.10	6.40	5.28	6.02
23952	9.85	9.65	6.22	6.04	6.08	6.50
26089	10.00	11.00	6.03	4.62	4.62	4.93
23946	3.84	7.46	5.26	4.32	3.78	3.83
26085	7.05	11.10	6.45	6.45	6.94	6.74
26823	14.80	11.20	6.55	7.18	6.80	7.50
26079	15.80	10.10	7.96	6.74	6.74	6.97
Average	10.02	9.17	6.01	5.44	5.32	5.54

the decrease in exchange capacity caused by each increase in strength of the acid is compared with the increase in alumina dissolved, the 1.0 N acid is found to dissolve the aluminum compounds which have the greatest effect on the exchange capacity, this being where the exchange capacity lost was, on an average, 10.0% of the M. E. of alumina dissolved. The effectiveness of the alumina decreased with an increase in the strength of the acid. That is to say, the compounds dissolved by the stronger acids have lower base-exchange capacities in proportion to the alumina dissolved than those which are dissolved by the weaker acids.

There was no relation between the decrease in total exchange capacity and the quantity of either ferric oxide or silica dissolved. The maximum quantity of ferric oxide was dissolved by 1.0 N acid. The quantities of silica dissolved by the acids were very small and decreased as the strength of the acid increased.

EFFECT OF DIGESTION WITH 0.5 N SODIUM HYDROXIDE FOLLOWING ACID DIGESTION

The less stable compounds when affected by acid digestion may rearrange into compounds which are similar but more stable and have less exchange capacity, or they may be broken down completely, leaving silica or silicic acid in the soil.

Treatment with acid did not completely destroy the base-exchange capacity of the soils studied, about 20% remaining after 10 hours heating with the strongest acid used. It has been claimed (5) that the power of the soil to exchange bases is due not to a base-exchange complex (consisting of compounds of alumina, bases, and silica), but to silicic acid. If such active silicic acid is present, it might be soluble in sodium hydroxide, so that extraction with sodium hydroxide would decrease the base-exchange capacity of the soil. In order to test this point, a set of untreated soils was digested in a boiling water bath for 10 hours with 0.5 N sodium hydroxide and the soluble alumina and silica and the exchange capacity of the residue determined. In another experiment 10 grams of soil were first treated with 1.0 N, 7.0 N, and 8.75 N acid as previously described. After filtering and washing, the residues were transferred to 500-cc Erlenmeyer flasks, 200 cc of 0.5 N sodium hydroxide added, and the suspension brought to a boil. Four grams of sodium chloride were added, the suspension quickly cooled, and filtered. The exchange capacities of the soil residues were determined. Silica was determined in the filtrate. The results are given in Table 4, except for 8.75 N acid which are not given because they are the same as those for 7.0 N acid.

Digestion with 0.5 N sodium hydroxide, not preceded by acid digestion, brought some silica into solution, but had very little effect upon the exchange capacity of the residue. However, the alkali treatment of the residue from the acid digestion still further reduced the exchange capacity of most soils. The decrease averaged 9% of the original exchange capacity of soils previously treated with 1.0 N acid and 13% of the capacity of the soils treated previously with 7.0 N acid. If the exchange capacity of the residue is placed at 100, the so-

TABLE 4.—*Soluble silica and reduction of exchange capacity caused by* 0.5 N *sodium hydroxide.*

Laboratory No.	Soluble silica			Reduction of exchange capacity due to NaOH				
				Original soil = 100			Residue from acid = 100	
	Alone, M.E.	After 1.0N acid, M.E.	After 7.0N acid, M.E.	None, %	1.0N acid, %	7.0N acid, %	1.0N acid, %	7.0N acid, %
25887......	108	505	750	2	14	18	28	64
31321......	174	554	880	0	14	15	26	65
29438......	109	307	860	0	16	6	27	38
31327......	200	727	1,230	0	25	13	38	68
29427......	89	408	930	2	2	16	4	59
23950......	72	344	1,060	2	0	11	0	55
23952......	61	435	1,130	2	0	10	0	59
26089......	68	502	1,220	1	4	14	8	64
23946......	64	498	1,540	2	7	18	22	78
26085......	110	602	1,170	2	7	13	28	72
26823......	90	690	1,300	1	11	17	24	77
26079......	78	738	1,400	0	5	11	8	73
Average....	102	526	1,123	1	9	13	18	64

dium hydroxide removed on an average 18% of the exchange capacity of the residue after 1.0 N acid and 64% of that remaining after the 7.0 N acid. The individual soils varied considerably from the average, especially when the original base-exchange capacity was used as a standard. The alkali digestion caused a reduction of 25% of the remaining exchange capacity of No. 31327 (after digestion with 1.0 N acid) and no reduction of that of Nos. 23950 and 23952. The effect of the alkali on the residue from digestion with 7.0 N acid was practically the same for all soils when the exchange capacity of the residue was 100. Apparently the strong 7.0 N acid decomposed the alumino-silicates to a greater extent than the 1.0 N acid.

The average quantities of silica dissolved by the alkali after treatment with 1.0 N and 7.0 N were 526 and 1,123 M. E., respectively. Evidently there was a considerable change in the nature of the silicate compounds or a greater production of silicic acid with an increase in the strength of acid used for the initial digestion. This is evident still further by a comparison of the quantity of destruction of the exchange capacity due to the alkali treatment. The alkali following the 1.0 N acid caused a further average decrease of only 2.4 M. E. of exchange capacity, although a considerable quantity of relatively unstable exchange complex was still left in the soil, as evidenced by the increased quantity destroyed by 1.75 N acid. After the digestion with 7.0 N acid, when comparatively small quantities of exchange capacity remained in the soil, which was not decreased by the treatment with 8.75 N acid, the alkali caused an average decrease of 4.3 M. E. of exchange capacity, or nearly twice as much as that caused by the same alkali treatment following the 1.0 N acid.

With the 1.0 N acid, the ratio of mols of silica made soluble in the alkali to mols of alumina soluble in the acid was 5 : 1, while the ratio of the increases of soluble silica to alumina was about 3 : 1 when the strength of acid was increased from 1.0 N to 7.0 N. This shows that the silica-alumina ratio of the exchange complex may vary significantly at different stages of decomposition.

EFFECT OF ACID DIGESTION ON MINERALS WHICH MAY OCCUR IN THE SOIL

The base-exchange capacity of soils has been held by Kerr (10, 11), Kelly and his coworkers (8, 9), and others to reside wholly or chiefly in bentonite. In order to determine whether the action of acid digestion on soils were similar to the action on certain soil minerals, five samples of minerals were treated in the same way as were the soils previously discussed. These included a sample of montmorillonite bentonite and one of Ordovician bentonite from Dr. C. S. Ross of the U. S. Geological Survey, a sample of dickite from the United States National Museum, and samples of kaolin from the Heil Corporation and from Eimer and Amend. Their respective total exchange capacities were 84.2, 29.4, 0.54, 4.34, and 3.68 M. E. per 100 grams. The destruction of the exchange complex of the minerals was not nearly so great as was that of the soils under similar treatment. The average destruction of the exchange capacity of the 12 soils by digestion with 1.75 N acid was 64%, while the corresponding decrease for the montmorillonite bentonite was 10% and for the Ordovician bentonite only 6%. The dickite and kaolin showed practically no decrease whatever. The quantity of aluminum dissolved by the 1.75 N acid from the montmorillonite bentonite was equivalent to 371 M. E. The ratio of M. E. of alumina to M. E. of exchange complex destroyed was 43.2, while for soils the corresponding average figure was 16.4. It seems probable, then, that either the bentonite of soils is sufficiently weathered so that the exchange complex breaks down in the soil much more readily than when the bentonite occurs in larger deposits, or a considerable part of the exchange capacity of soils is due to other minerals which are decomposed by acids much more easily than bentonite.

Further evidence that bentonite behaves differently from the soil is found in the work of Kerr (10), who found that a sample of bentonite with an exchange capacity of 97.7 M. E. had 66 M. E. exchange capacity after 6 hours digestion with boiling 0.2 N hydrochloric acid and extraction of the silica with sodium carbonate. He found that the exchange capacities of two samples of bentonite were completely destroyed by 12 hours boiling with normal hydrochloric acid and extraction with sodium carbonate. On an average, only 85% of the exchange capacity of the soils here studied were destroyed by a similar treatment. This indicates that minerals other than those contained in bentonite similar to that studied are responsible for at least a part of the base exchange capacity of soils.

DISCUSSION

The results reported indicate the presence of a series of alumino-silicic acids in the base exchange complex, varying in quantity, relative proportions, and activity in the different soils. Bradfield (2, 3, 4) suggested the presence of a series of similar acids in the exchange complex. His explanation for obtaining a typical monobasic acid titration curve for his colloids is that a mixture of acids with unlike dissociation constants may give a monobasic curve if their respective constants are close enough together so that their individual curves overlap. Varying proportions of the different acids would probably give slightly different curves. The work of Fraps and Fudge (6), Pierre and Scarseth (14), and others shows differences in the exchange complexes of different soils which can best be explained on the basis of such a series of acids. Fudge (7) has recently shown that there are significant differences in the quantities of potassium and ammonium fixed from dilute solutions per unit of exchange capacity of different soils. The work reported here indicates the presence of compounds comparatively unstable to acids in some soils, and their absence in others. Soils Nos. 29438 and 29427 in particular show the presence of such compounds. Under the influence of comparatively weak acids, the exchange capacity of these soils is considerably reduced with solution of a comparatively small amount of alumina. This indicates the presence of relatively unstable, easily decomposable compounds. Other soils, for example, Nos. 25887 and 31321, do not contain such compounds. The exchange complexes of these soils are apparently much more uniform and are probably composed of fewer exchange acids. It is interesting to note that after the comparatively unstable compounds have been decomposed, all of the soils tend to have similar ratios between decrease of the remaining exchange capacity and soluble aluminum.

The evidence here discussed offers only indications, since the acid no doubt dissolves other alumina besides that in the exchange complex, and the exchange compounds may be decomposed by the acid with a partial solution of the alumina and the formation of compounds containing lower percentages of alumina.

Exchange compounds containing silica which is soluble in 0.5 N sodium hydroxide are formed only after considerable quantities of alumina have been removed from the original exchange compounds by acid digestion. The average amount of silica rendered soluble in alkali by 7.0 N acid was equivalent to 282 millimols per 100 grams of soil, while the average amount of alumina removed from the soils was but 81 millimols.

SUMMARY

The coefficient of correlation between the total exchange capacities of 259 soils and the percentages of iron and aluminum oxides soluble in hydrochloric acid of 1.115 sp. gr. was $+ .878 \pm .010$.

Digestion in boiling water for 10 hours with 0.2, 1.0, 1.75, 3.50, 7.00, and 8.75 N hydrochloric acid reduced the average total exchange capacities of 12 soils 17, 47, 64, 74, 80, and 80%, respectively.

When the alumina dissolved by the 7.0 N acid was placed at 80, the relative quantities of alumina dissolved were 10, 30, 58, 76, 84, and 80%. The correlation coefficient between the loss of exchange capacity and the quantity of alumina dissolved by the various strengths of acids was .859 ± .029. The average decreases in M. E. of total exchange capacity expressed as percentages of M. E. of soluble alumina were 10.0, 9.2, 6.0, 5.4, 5.3, and 5.5.

No relation was apparent between decrease in total exchange capacity and the ferric oxide dissolved.

The ratio of decrease in total exchange capacity to alumina dissolved varied with individual soils, especially with 0.2 N and 1.0 N hydrochloric acid. With stronger acids, the relation between decreased total exchange capacity and soluble alumina was fairly constant.

When the quantity of alumina soluble in the various acids is expressed as M. E., the decrease in total exchange capacity was about 10% of the alumina dissolved with dilute acids but only 5.4% with the stronger acids. This indicates a difference in the nature of the compounds of the exchange complex acted upon by the different strengths of acid.

Digestion with 0.5 N sodium hydroxide of the original soil and the residues from 1.0 N and 7.0 N hydrochloric acid still further decreased the exchange capacity 1, 9, and 13% of the original capacity, or 0.3, 2.4, and 4.3 M. E., respectively. Silica in the sodium hydroxide extract amounted to 102, 526, and 1,123 M. E. The relation between the silica dissolved and decrease in exchange capacity was very small.

The exchange capacities of two samples of bentonite digested with acid were destroyed to a much smaller degree than were those of soils receiving similar acid treatment. Minerals other than bentonite appear to be responsible for a considerable proportion of the exchange complex of soils.

The exchange capacities of a sample of dickite and two of kaolin were not affected by acid digestion.

The results indicate the presence of a series of aluminosilicic acids in the exchange complex, varying in different soils with respect to strength, stability, and relative proportions.

LITERATURE CITED

1. BAVER, L. D., and SCARSETH, G. D. The nature of soil acidity as affected by the SiO_2-Sesquioxide ratio. Soil Science, 31: 159–173. 1931.
2. BRADFIELD, RICHARD. The saturation capacity of colloidal clay soils. Proc. 1st. Int. Soil Cong., 4: 858–868. 1928.
3. ——————. The effect of the concentration of colloidal clay upon its hydrogen-ion concentration. Jour. Phys. Chem., 28: 170–175. 1924.
4. ——————. The nature of the chemical reaction of colloidal clay. Colloid. Sym. Mon., 1: 369–391. 1923.
5. BRITTON, H. T. S. Hydrogen Ions, Their Determination and Importance in Pure and Industrial Chemistry. New York: D. Van Nostrand Co., Inc. 1929.
6. FRAPS, G. S. and FUDGE, J. F. Relation of buffer capacity for acids to basicity and exchangeable bases of the soil. Texas Agr. Exp. Sta. Bul. 442. 1932.
7. FUDGE, J. F. Mathematical relations between total exchange capacity and absorption of ammonium and potassium by soils. Soil Science, In press. 1935.

8. KELLY, W. P., and BROWN, S. M. Ion exchange in relation to soil acidity. Soil Science, 21: 289–302. 1926.
9. ———, DORE, W. H., and BROWN, S. M. The nature of the base-exchange material of bentonites, soils and zeolites, as revealed by chemical investigations and X-ray analysis. Soil Science, 31: 25–45. 1931.
10. KERR, H. W. The identification and composition of the soil alumino-silicate active in base-exchange and soil acidity. Soil Science, 26: 385–398. 1928.
11. ———. The nature of base exchange and soil acidity. Jour. Amer. Soc. Agron., 20: 309–335. 1928.
12. McGEORGE, W. T. The base-exchange properties of soil organic matter. Jour. Amer. Soc. Agron., 23: 331–336. 1931.
13. MATTSON, A. The relation between the electrokinetic behavior and the base-exchange capacity of soil colloids. Jour. Amer. Soc. Agron., 18: 458-470. 1926.
14. PIERRE, W. H., and SCARSETH, G. D. Determination of the percentage base saturation of soils and its value in different soils at definite pH values. Soil Science, 31: 99–114. 1931.
15. ROBINSON, G. W. Soils: Their Origin, Constitution, and Classification. London: Thomas Murby & Co. 1932.
16. SCARSETH, GEORGE D. Morphological, greenhouse, and chemical studies of the Black Belt soils of Alabama. Ala. Agr. Exp. Sta. Bul. 237. 1932.

STUDIES OF THE INHERITANCE OF AND THE RELATIONSHIPS BETWEEN KERNEL TEXTURE, GRAIN YIELD, AND TILLER-SURVIVAL IN CROSSES BETWEEN REWARD AND MILTURUM SPRING WHEATS[1]

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HARD kernel texture in bread wheats is generally associated with high protein content, and with high milling and baking qualities. The opinion is held that the texture of the kernels is determined almost entirely by the climatic conditions under which the wheat is grown. Recent investigations (1, 2, 3)[3] at the University of Alberta, Edmonton, Canada, have indicated that soil and heredity play a much greater part in influencing the bread-making qualities of wheat than has generally been accepted. Intensive studies are being made on the influence of black and gray soils on the kernel texture, protein content, and baking qualities of several wheat varieties (1,2). The mode of inheritance of kernel texture, protein content and baking quality in several wheat crosses is also being studied under the same conditions (3).

Bryan and Pressley (7) have recently called attention to the possible connection between texture of kernels and tillering in Early Baart wheat. As one phase of the general studies mentioned above, the writers of the present paper were interested in determining the interrelationships existing in the number of tillers per plant, grain yield, and texture of kernels in segregating populations from crosses between Reward and Milturum spring wheats.

MATERIALS AND METHODS

MATERIALS

Eight entire F_2 populations and 100 F_3 lines of Reward X Milturum were used in the present study. Reward, C. A. N. 1509,[4] is a hard red spring wheat originating from a Marquis X Prelude cross, at the Central Experimental Farm, Ottawa. It is fair in yielding ability, possesses exceptionally good baking quality, and produces a kernel of vitreous texture even when grown on the gray wooded (Fallis, Alberta) soil (podsol). Milturum 0.321, C. A. N. 1415, is a soft red spring wheat obtained in 1928 from Dr. Talanov of the West Siberian Experimental Station, U. S. S. R. It is high in yielding ability, possesses poor baking quality, and produces a kernel of starchy texture even when grown on the black (Edmonton) soil (chernozen).

[1]Contribution from the Department of Field Crops, University of Alberta, Edmonton, Canada. Published as paper. No. 75 of the Associate Committee on Grain Research of the National Research Council and the Dominion Dept. of Agriculture. Received for publication March 12, 1935.

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[3]Reference by number is to "Literature Cited", p. 465.

[4]C. A. N. = Canadian Accession Number.

EXPERIMENTAL METHODS

The crosses between Reward and Milturum were made at the University of Alberta, Edmonton, Canada, in 1929. The F_1 plants were grown in the field in 1930. There was no indication of sterility in any of the crosses.

A number of the F_2 populations were grown at Edmonton, Alberta, in 1932. Eight F_2 populations and 100 selected F_3 lines were grown at Fallis, Alberta, in 1933. The selection of the F_3 lines was based on the kernel texture of the F_2 plants grown at Edmonton in 1932. Of these plants, four groups of 25 each were used. The kernel texture of the respective groups were completely vitreous, vitreous with a trace of starchiness, starchy with a trace of vitreousness, and completely starchy.

The material was grown in 5-foot rows, 1 foot apart, with 25 spaced seeds per row. Parental replications were made every 30 rows. Each plant was harvested and threshed individually. The number of culms per plant was recorded at harvest. The data obtained from the classification of the material for the various characters for each F_2 population originating from a different F_1 plant were recorded separately and combined only after it was ascertained that there was no significant difference between the different populations. The significance of the correlation coefficients was determined by the method suggested by Fisher (17).

INHERITANCE OF KERNEL TEXTURE

Considerable controversy exists in regard to the relative weight that should be attached to the several factors influencing the kernel texture of wheat. The opinion is held that the kernel texture of wheat is determined primarily by the climatic conditions under which it is grown. Genetic studies have shown definitely that there exists inherent differences for kernel texture among the different wheat varieties. Recent investigations (2, 3) at the University of Alberta, have shown that a very satisfactory method of studying the inherent differences in kernel texture between wheat varieties is to use material grown under a special environment in regard to soil and climate.

The environmental conditions at Edmonton usually are such that wheat varieties grown there differ little in kernel texture, with the exception of those varieties which possess very poor quality, like Milturum. However, in 1932, due both to climatic conditions and to the great difference in the kernel texture of the parents, a good differentiation for this character was obtained at Edmonton. In order to avoid this uncertainty of obtaining a differentiation at Edmonton, texture studies are conducted at Fallis, Alberta, 50 miles west of Edmonton, in the gray wooded soil (podsol) area. In this district the soil and climatic conditions are such as to result in a good differentiation for kernel texture of wheat every year. A description of the soil of this area is given by Wyatt and Newton (30).

A complete review of the literature on kernel texture of wheat is reported by Aamodt and Torrie (2, 3). The number of factor pairs found to govern the mode of inheritance of kernel texture by the different investigators is as follows: Biffen (4) and Bryan and Pressley (6, 7), one factor pair; Engledow and Hutchinson (16) and Freeman (19), two factor pairs; and Harrington (21) and Clark, Florell, and Hooker (11), several factor pairs. Aamodt and Torrie (3), in crosses

between Selection I–28–60 X Milturum 0.321, found that certain F_2 populations indicated a partial dominance of vitreous texture by two main factor pairs, others by one main factor pair; while in still a third group starchy texture was partially dominant by one main factor pair. The presence of minor modifying factors, influencing the expression of the main factor pairs, was reported by both Aamodt and Torrie (3) and Bryan and Pressley (7).

EXPERIMENTAL RESULTS

The inheritance of kernel texture was studied in the F_1 and F_2 grown at Edmonton in 1930 and 1932, respectively, and in the F_2 and F_3 grown at Fallis in 1933. In every instance a good differentiation for kernel texture was obtained. The material was classified for this character by assigning values from 1 to 10, "1" being completely starchy and "10" completely vitreous.

The texture of the seed from the F_1 plants was completely starchy, indicating a complete dominance of the starchy endosperm. The four groups of selected F_2 plants of Reward X Milturum were also classified for kernel texture as described previously. The distribution, mean, and standard deviation for kernel texture, as shown by data in Table 1, are essentially similar for both generations of hybrids. The correlation coefficient between the F_2 and F_3 kernel texture was +0.749 (P value <0.01), which clearly indicates the heritable nature of kernel texture.

TABLE 1.—*Frequency distribution, mean, and standard deviation for kernel texture index of Reward x Milturum selected plants grown at Edmonton in 1932 and the corresponding F_3 and parental lines grown at Fallis in 1933.*

Cross or parent*	Classes for kernel texture										Total number	Mean kernel texture	Standard deviation
	1	2	3	4	5	6	7	8	9	10			
					1932								
F_2 Edmonton......	3	16	17	6	6	12	12	10	9	5	96	5.3±0.27	2.7±0.19
					1933								
P^3 Reward	—	—	—	—	—	—	—	—	2	4	6	9.7±0.21	0.4±0.14
P^3 Milturum.....	2	4	—	—	—	—	—	—	—	—	6	1.7±0.21	0.4±0.14
F_3 Fallis	—	7	16	17	24	14	12	2	4	—	96	4.9±0.18	1.7±0.12

*The kernel texture of the P_2 parents was Milturum 1 and Reward 10.

The difference between the mean kernel texture index of any of the F_2 populations grown at Fallis in 1933, and that of the one with the mean closest to it was not significant. A significant difference of 1.3±0.29 was obtained between the F_2 populations having the highest and lowest mean value for texture index. The slight variability found in the means of the several F_2 populations is probably due to the presence of minor modifying factors. Since these differences are not very great, the data obtained from the several F_2 populations are treated collectively and are given in Table 2.

TABLE 2.—*Frequency of distribution, mean, and standard deviation for kernel texture of Reward x Milturum F_2 populations treated collectively and for parental plants grown at Fallis in 1933.*

Parent or cross	Classes for kernel texture										Total number	Mean kernel texture	Standard deviation
	1	2	3	4	5	6	7	8	9	10			
Reward....	—	—	—	—	—	—	2	2	18	52	74	9.6±0.08	0.6±0.05
Milturum..	28	56	8	—	—	—	—	—	—	—	92	1.8±0.06	0.6±0.05
F_2.........	43	92	103	112	148	127	79	79	63	18	864	5.1±0.08	2.3±0.06

The variability of the hybrids is significantly greater that that of either parent, clearly indicating that segregation has occurred. The distribution of the hybrids approaches that of a normal curve, which suggests that the inheritance of kernel texture, in these crosses is governed by polymeric (multiple) factors.

The heritable nature of kernel texture, as shown by the data reported herein, is in agreement with the conclusions obtained by other investigators studying the inheritance of this character in wheat crosses. The lack of agreement in the factorial explanations obtained by the several workers is to be expected, owing to the different varieties used as parents and the conditions under which the material was grown.

INHERITANCE OF GRAIN YIELD

Clark (10) states that, "Yield may be considered as a character complex affected by environment and by most of the morphological and physiological characters of the plant." Inheritance studies on grain yield in spring wheat crosses have been made by a number of investigators (10, 11, 12, 13, 14, 15, 27, 28). The results obtained by Clark and his co-workers (11, 12) show the great influence that different environmental conditions have upon grain yield. Transgressive segregation for the inheritance of grain yield was reported by several investigators (11, 12, 14, 28). A partial dominance of the high-yielding parent was obtained by several workers (10, 14, 15). Torrie (27), from the study of the F_3 of Reward X Caesium, reports that the inheritance of grain yield appeared to be governed by a number of polymeric factors, with a partial dominance of the low yield of Reward.

EXPERIMENTAL RESULTS

The individual plant yield of grain in grams was determined for the eight F_2 populations and the parents of Reward X Milturum grown at Fallis in 1933. The average grain yield and standard deviation for each F_2 population and the parents were calculated. The data are given in Table 3.

The data in Table 3 show that the differences between the several F_2 populations are not significant, with the exception of F_2 population 2005. No satisfactory explanation for the low yield of the F_2 population 2005 can be offered. Because its average yield differs signifi-

TABLE 3.—*Mean and standard deviation for grain yield in grams of Reward x Milturum F_2 populations and parental plants grown at Fallis in 1933.*

Parent or F_2 population	Number of plants	Mean grain yield	Standard deviation
Reward	75	4.2±0.27	2.5±0.21
Milturum	91	7.0±0.38	3.7±0.27
1999	118	4.6±0.27	2.9±0.16
2000	156	4.8±0.22	2.8±0.19
2001	14	4.9±0.80	3.5±0.64
2002	106	4.6±0.25	2.5±0.18
2003	92	4.4±0.30	2.7±0.21
2004	114	4.5±0.22	2.4±0.15
2005	127	3.3±0.18*	1.9±0.12
2006	137	4.7±0.18	2.1±0.13
Total and averages for the F_2	737	4.6±0.09	2.6±0.06

*Not included in average.

cantly from those of the other F_2 populations, it is not included in the average. The difference in the grain yield between Reward and Milturum of 2.8±0.48 grams is evidently very significant. The variability of grain yield of Reward, as measured by the standard deviation, and the average of the F_2 populations are practically the same, while that of Milturum is significantly higher. The average yield of the F_2 populations tends to that of the low-yielding parent Reward, which suggests a dominance of low yield.

It is very difficult to arrive at any satisfactory factorial explanation of grain yield, particularly in an F_2 population, where the yield is based entirely upon individual plants. This difficulty is due largely to the varying effect of environmental factors on the grain yield of the individual plants in an F_2 population. Torrie (27) has shown that the average plant yield of an F_3 row gives a much better indication of the yielding ability of a line than that of an individual F_2 plant. Although no satisfactory genetic explanation can be offered for the inheritance of grain yield, the results are in agreement with those of other workers in showing the complex nature of the mode of inheritance for this character.

INHERITANCE OF NUMBER OF MATURE CULMS

Grantham (20) reports that the capacity for tillering, in winter wheat is a varietal characteristic. Stewart (26) found no segregation for the number of culms in crosses between Dicklow and Sevier. Helgendorf (22) found differences both in the number of tillers produced and the tiller survival among a number of wheat varieties grown in New Zealand. Bridgford and Hayes (5), from a study of factors affecting yield in hard red spring wheat, report that in the number of heads per row, which is a measure of tillering ability, the N. D. 1656 selections and other Kota-Marquis crosses were relatively low, whereas Hope, Marquillo, H_{44}, and most of the double crosses excelled in this respect. Clark and Wilson (8) found no genetic differences in the tillering rates of 24 varieties of durum spring wheats.

EXPERIMENTAL RESULTS

The number of tillers which produced mature heads (tiller survival) was counted at harvest for both the F_2 and the F_3 of Reward X Milturum grown at Fallis. In Table 4 are presented data which give the mean and standard deviation of Reward X Milturum F_2 populations and parental plants for tiller survival.

TABLE 4.—*The mean and standard deviation for tiller survival of Reward x Milturum F_2 populations and parental plants grown at Fallis in 1933.*

Parent or F_2 population	Number of plants	Mean tiller survival	Standard deviation
Reward	75	6.3±0.31	2.6±0.6
Milturum	91	7.2±0.18	3.3±0.11
1999	118	6.9±0.25	2.8±0.15
2000	156	6.4±0.22	2.7±0.18
2001	14	6.2±0.89	3.4±0.64
2002	106	6.5±0.27	2.9±0.19
2003	92	6.2±0.25	2.4±0.18
2004	114	5.5±0.19	2.0±0.13
2005	127	5.2±0.16	1.8±0.12
2006	137	5.1±0.18	2.1±0.12
Total and averages for the F_2	864	6.0±0.09	2.6±0.06

The difference in the mean tiller survival of any F_2 population and the one with its mean closest to it is not significant. However, the difference in tiller survival of 1.8±0.31 between the high F_2 population 1999 and the low F_2 population 2006 is significant. Soil heterogeneity rather than genetic factors are believed to have resulted in the significant differences between these two F_2 populations. This is borne out by the data in Table 4 which show a progressive decrease in the average tiller survival per F_2 population from F_2 population 1999 to 2006. The material was grown in the field in the same order as presented in Table 4. The difference between the parents of 0.90±0.37 tillers is barely significant. The mean of all the F_2 populations is slightly less than that of Reward, the low parent. The variability of the F_2 populations is less than that of either parent.

The data in Table 5 are based on the average tiller survival of Reward X Milturum F_3 lines and parental rows grown at Fallis in 1933. The differences in both the mean and standard deviation between the parents and hybrids are not significant.

TABLE 5.—*Frequency distribution, mean, and standard deviation for tiller survival of Reward x Milturum F_3 lines and parental rows grown at Fallis in 1933.*

Parent or cross	Classes for tiller survival									Total number	Mean tiller survival	Standard deviation
	4	5	6	7	8	9	10	11	12			
Reward	1	—	2	1	2	—	—	—	0	6	6.5±0.57	1.4±0.41
Milturum	—	1	1	2	—	2	—	—	—	6	7.2±0.60	1.5±0.45
F_3 lines	2	13	14	35	19	12	—	1	1	97	7.1±0.15	1.4±0.11

Both the F_2 and F_3 data show, that for the conditions of the experiment, there is no genetical difference in the tiller survival of Reward and Milturum.

ASSOCIATIONS AMONG CHARACTERS STUDIED

It is very important in a plant breeding study to have a knowledge of the relationships existing among or between each pair of characters. Selection may be greatly facilitated if it is shown that a readily classifiable character is linked with a complex character. Such studies also indicate the extent to which the various desirable characters of each parent are associated with each other and the possibilities of obtaining suitable recombinations in the hybrids. The various relationships existing among tiller survival, grain yield, and kernel texture are shown by the simple and first order partial correlation coefficients given in Table 6.

TABLE 6.—*Simple and first order partial correlation coefficient between kernel texture, grain yield, and tiller survival for the F_2 and between kernel texture and tiller survival for the F_3 of Reward x Milturum grown at Fallis in 1933.*

Number of samples	Generation	Simple correlations		Partial correlations	
		Variables correlated*	r	Variables correlated	r
737	F_2	TY	+0.078	TY.S	—0.066
737	F_2	SY	+0.780†	SY.T	+0.784†
737	F_2	TS	+0.152†	TS.Y	+0.146†
98	F_3	TS	+0.279†	——	——

*T = kernel texture; Y = grain yield; S = tiller survival.
†P value exceeds the 1% point.

KERNEL TEXTURE AND GRAIN YIELD

Freeman (18) studied the relative yielding ability of hard- and soft-textured wheat grown in mechanical mixtures. He found with Turkey wheat a negative correlation, while with durum wheats he obtained a positive correlation between grain yield and hard texture. Bryan and Pressley (7) studied the yielding ability of a number of hard and soft texture strains of Baart wheat. They found that the soft strains yielded the highest. This, they state, explains the progressive increase in the percentage of soft kernels found over a 6-year period in mechanical mixtures of soft- and hard-textured strains.

The simple correlation coefficient between kernel texture and grain yield for the F_2 of Reward X Milturum grown at Fallis was +0.078. By the use of the partial correlation coefficient in which tiller survival was held constant, a correlation of —0.066 was obtained. These correlations have a P value greater than 0.05 and consequently indicate that there is no relationship between kernel texture and grain yield. The results indicate that there should be no trouble in securing vitreous texture lines from the material studied for Fallis conditions without suffering a loss in yield. The disagreement be-

tween the conclusions of this investigation and those of other workers (7, 18) is probably due to differences both in the material used and in the environmental conditions under which it was grown.

TILLER SURVIVAL AND GRAIN YIELD

Clark (9) reports a positive correlation between the extent of tillering and the grain yield of barley. Grantham (20) found for winter wheat that increased yield is associated with an increase in the number of tillers up to four or five. Smith (24) found no close relationship to exist between the extent of tillering and grain yield from a study of rod row trials of wheat, oats, and barley. He cites the work of Love and Leighty with oats and Vestergaard with barley, both of whom report a positive correlation between tillering and yield. He also cites the work of Buffum, Schribaux, Gericke, Leschenko, and Opeta, all of whom record disadvantages with too much tillering. Sprague (25) and Quisenberry (23) both found that the number of heads per unit area was one of the most important factors in determining grain yield. Bridgford and Hayes (5) obtained a positive but non-significant correlation between grain yield and number of spikes per row from rod row trials of spring wheat. In this study, two main groups of strains were included, the Minnesota double crosses, which excelled in heads per row, and the Kota crosses, which lacked stooling ability. Since certain strains of both groups excelled in yield, the correlation between yield and heads per row was not significant. Waldron (29) obtained a partial correlation of +0.933 between spikes per row and grain yield, holding grains per spike constant, from which he concludes that, with respect to yield, these two components form nearly or quite a closed system.

The simple correlation coefficient between grain yield and tiller survival for the F_2 populations of Reward X Milturum grown at Fallis was +0.780. Holding grain texture constant, the partial correlation was +0.784. These correlations indicate that, under the conditions of the experiment, there exists a definite relationship between grain yield and tiller survival.

KERNEL TEXTURE AND TILLER SURVIVAL

Bryan and Pressley (7) grew soft and hard strains of Baart wheat spaced 3 inches each way. From their data they concluded that the soft strains not only produced more heads per plant with close spacing than the hard strains, but as the amount of space per plant increases the difference in the number of heads per plant increases proportionately.

The relationship between kernel texture and tiller survival was studied in the F_2 and F_3 of Reward X Milturum grown at Fallis. The simple correlation coefficients between grain texture and tiller survival for the F_2 populations and F_3 lines were +0.152 and +0.279, respectively. In the F_2, holding grain yield constant, the first order partial correlation was +0.146. These correlations are statistically significant and indicate a slight tendency for the plants possessing kernels of vitreous texture to have a higher tiller survival than those with starchy texture.

In Table 7 the data show the average tiller survival for the different texture classes of Reward X Milturum F_2 populations and F_3 lines grown at Fallis in 1933.

TABLE 7.—*Average tiller survival for the different texture indices of the F_2 plants and the F_3 lines of Reward x Milturum grown at Fallis in 1933.*

Texture index	Tiller survival			
	F_2		F_3	
	Number of plants	Mean	Number of lines	Mean
1	43	5.9±0.28	—	—
2	92	6.1±0.18	7	6.3±0.34
3	103	6.2±0.24	16	7.2±0.44
4	112	5.9±0.21	17	6.5±0.29
5	148	6.5±0.25	24	6.8±0.24
6	127	6.9±0.24	15	7.8±0.30
7	79	7.1±0.27	12	6.9±0.25
8	79	6.9±0.34	2	8.0±0.72
9	63	7.3±0.43	4	8.8±0.66
10	18	6.6±1.08	—	—
Total and average for the F_2 and F_3	864	6.0±0.09	96	7.1±0.15

The results show a more or less progressive tendency for increased vitreousness of kernel texture in the sample to be associated with an increase in tiller survival. These data support the evidence obtained from the correlation studies between kernel texture and tiller survival that the F_2 plants and F_3 lines producing kernels of vitreous texture tend to have a higher tiller survival than the F_2 plants and F_3 lines with kernels of starchy texture. The results of this investigation are in disagreement with those obtained by Bryan and Pressley (7). This is probably due both to the different material used and to the different environmental conditions under which the experiment was conducted.

SUMMARY

Crosses between Reward and Milturum were studied genetically for the inheritance of and the relationship between the characters of kernel texture, grain yield, and tiller survival. Part of the F_2 populations and selected F_3 lines were grown at Fallis, Alberta, in order to secure a satisfactory differentiation for kernel texture.

The inheritance of kernel texture appeared to be explainable on the assumption of polymeric factors. Starchy texture was dominant to vitreous texture.

The inheritance of grain yield appeared to be of a complex nature. A partial dominance of low yielding factors was indicated.

No genetic difference was obtained in the tiller survival of Reward and Milturum grown at Fallis.

No genetic relationship was found between grain yield and kernel texture.

A highly significant positive correlation was obtained between grain yield and tiller survival.

A small but significant association was obtained between vitreous kernel texture and high tiller survival.

LITERATURE CITED

1. AAMODT, O. S., and MCCALLA, A. G. Quality and keeping properties of flour from wheat grown on black and gray soils in Alberta. Can. Jour. Res. In press. 1935.
2. ———————, and TORRIE, J. H. Kernel texture as an indicator of quality in hard red spring wheats. Can. Jour. Res. In press. 1935.
3. ———————, ———————. Studies on the inheritance of and the relationship between kernel texture and protein content in several spring wheat crosses. Can. Jour. Res. In press. 1935.
4. BIFFEN, R. H. Mendel's laws of inheritance and wheat breeding. Jour. Agr. Sci., 1: 4–48. 1905.
5. BRIDGFORD, R. O., and HAYES, H. K. Correlation of factors affecting yield in hard red spring wheat. Jour. Amer. Soc. Agron. 23: 106–117. 1931.
6. BRYAN, W. E. and PRESSLEY, E. H. Plant breeding. Ariz. Agr. Exp. Sta. Ann. Rpt., 1920: 480–483. 1920.
7. ———————, ———————. Hard grain texture of wheat in mechanical mixtures and in crosses. Jour. Amer. Soc. Agron., 25: 64–69. 1933.
8. CLARK, E. R., and WILSON, H. K. Lodging in small grains. Jour. Amer. Soc. Agron., 25: 561–572. 1933.
9. CLARK, J. A. A statistical study of barley at Dickinson, North Dakota. Jour. Amer. Soc. Agron., 6: 183–185. 1914.
10. ———————. Segregation and correlated inheritance in crosses between Kota and Hard Federation wheats for rust and drought resistance. Jour. Agr. Res., 29: 1–47. 1924.
11. ———————, FLORELL, V. H., and HOOKER, J. R. Inheritance of awnedness, yield and quality in crosses between Bobs, Hard Federation and Propo wheats at Davis, California. U. S. D. A. Tech. Bul. 39. 1928.
12. ———————, and HOOKER, J. R. Segregation and correlated inheritance in Marquis and Hard Federation crosses, with factors for yield and quality of spring wheat in Montana. U. S. D. A. Bul. 1403. 1926.
13. ———————, and QUISENBERRY, K. S. Inheritance of yield and protein content in crosses of Marquis and Kota spring wheats grown in Montana. Jour. Agr. Res., 38: 205–217. 1929.
14. ———————, ———————, and POWERS, L. Inheritance of bunt reaction and other characters in Hope wheat crosses. Jour. Agr. Res., 46: 413–425. 1933.
15. ———————, and SMITH, R. W. Inheritance in Nodak and Kahla durum wheat crosses for rust resistance, yield and quality at Dickinson, North Dakota. Jour. Amer. Soc. Agron., 20: 1297–1304. 1928.
16. ENGLEDOW, F. L., and HUTCHINSON, J. B. Inheritance in wheat. II. *T. turgidum* x *T. durum* crosses, with notes on the inheritance of solidness of straw. Jour. Gen., 16: 19–32. 1926.
17. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1932.
18. FREEMAN, G. F. A mechanical explanation of the progressive change of proportion of hard and soft wheat kernels. Jour. Amer. Soc. Agron., 10: 23. 1918.
19. ———————. Producing bread-making wheats for warm climates. Jour. Her., 9: 211–226. 1918.
20. GRANTHAM, A. E. The tillering of winter wheat. Del. Agr. Exp. Sta. Bul. 117. 1917.
21. HARRINGTON, J. B. The mode of inheritance of certain characters in wheat. Sci. Agr., 2: 319–324. 1922.
22. HELGENDORF, F. W. Third Annual Report. Wheat Research Institute, N. Z. Dept. Sci. and Ind. Res. Bul. 42. 1932.
23. QUISENBERRY, K. S. Some plant characters determining yield in fields of winter and spring wheat in 1926. Jour. Amer. Soc. Agron., 20: 492–499. 1928.

24. SMITH, R. W. The tillering of grain as related to yield and rainfall. Jour. Amer. Soc. Agron., 17: 717–724. 1925.
25. SPRAGUE, H. B. Correlations and yield in bread wheats. Jour. Amer. Soc. Agron., 18: 971–996. 1926.
26. STEWART, G. Correlated inheritance in a cross between Dicklow x Sevier wheat. Jour. Amer. Soc. Agron., 23: 916–929. 1931.
27. TORRIE, J. H. Studies on the inheritance of, and the relation between certain physiologic and morphologic characters in several wheat crosses. Unpublished master's thesis, University of Alberta, Edmonton, Canada. 1934.
28. WALDRON, L. R. Hybrid selections of Marquis and Kota. N. D. Agr. Exp. Sta. Bul. 200. 1926.
29. ———————. Yield and protein content of hard red spring wheat under conditions of high temperature and low moisture. Jour. Agr. Res., 47: 129–147. 1933.
30. WYATT, F. A., and NEWTON, J. D. Wooded soils and their management. Univ. Alberta Col. Agr. Bul. 21. 1932.

THE INFLUENCE OF LOW TEMPERATURE ON SEEDLING DEVELOPMENT IN TWO INBRED LINES OF CORN[1]

OLIVER F. SMITH[2]

THE growth and development of corn seedlings at low temperatures is primarily dependent upon their ability to develop chlorophyll, the efficiency with which they utilize their endosperm reserves, and their ability to build tissues which resist the attack of seedling blight organisms. Observations have shown that seedlings of inbred lines of corn respond differently when grown at low temperatures. Some are able to synthesize chlorophyll, make an efficient use of their endosperm reserves, and develop tissues which resist the attack of soil-borne parasites, while others do not develop chlorophyll, make an inefficient use of their endosperm reserves, and are susceptible to the attack of soil-borne parasites.

Owing to the need of extending the growing season for corn in the northern portion of the United States, corn is planted early, which often subjects it to low temperatures during the early seedling stages of development. For this reason it seemed desirable to study differences in the reactions of seedlings, to determine convenient methods of measuring and evaluating seedling response to low temperatures, and ultimately to correlate these responses with later development both in the inbreds and in the hybrid combination.

METHODS AND MATERIALS

The inbreds RYD_4 and GG_{26} produced at the Wisconsin Experiment Station and inbred for 10 years were chosen for this study because of their marked contrast in response to low temperature. RYD_4 shows a more stable type of development with the formation of chlorophyll at the lower temperatures (17°C), whereas GG_{26} is less stable in its reaction and is chlorotic at a temperature of 17°C. Both inbreds are green when grown at a temperature of 24°C. All results reported here are from experiments with these two inbreds and subsequent generations produced by selfing or hybridizing these lines.

Unless otherwise stated, the seedlings were grown in the greenhouse during the winter. The greenhouses were maintained at temperatures of 17° and 24°C, with an average fluctuation in temperature of about 2 degrees above and below the desired temperatures.

The houses will be referred to in the discussion as the 24° and the 17°C houses, respectively. When it was necessary to change the temperature at which a given lot of seedlings was growing, the plants were moved to the house which was being held at the desired temperature.

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TEMPERATURE AND PIGMENT FORMATION

The difference in the ability of these inbred lines of corn to form chlorophyll at low temperatures was very striking, especially at 16° to 19°C. When grown at this temperature range the seedlings of GG_{26} were typically of the virescent type. The young plants were practically without chlorophyll except at the extreme tips of the leaves where chlorophyll sometimes developed in small amounts. Later during the course of their development, these seedlings gradually developed a slight yellowish color. There was, however, considerable range in pigment formation among the individuals in a given population. Some were nearly pure white with only a faint suggestion of yellow or green color at the leaf tips, while others were a light yellow to greenish yellow rather than yellowish white in color. A given population usually represented all gradations between these limits. In contrast, the seedlings of RYD_4, grown at the same temperature, showed normal pigment development. The differences in pigment formation shown by these two seedling types were so marked that it seemed to warrant further investigations, especially on the effect of low temperatures on the formation of chlorophyll and other associated pigments and their relation to seedling metabolism and growth.

QUANTITATIVE DETERMINATIONS OF CHLOROPHYLL AND CAROTINOID PIGMENTS

It is well known that accompanying chlorophyll are two yellowish pigments, carotin and xanthophyll, which are known as the carotinoids. (A third pigment, fucoxanthin, occurs in brown algae.) Little is known regarding the formation of these pigments by the plants and their relation to each other. Results of other workers (7, 8, and 11)[3] suggest, however, that a close correlation exists between the formation of chlorophyll and at least one of the carotinoid pigments. The purpose of these experiments was to determine to what extent the formation of the carotinoid pigments in these corn seedlings is affected by low temperature, especially in relation to chlorophyll development.

Pigment extractions were made from fresh plant tissue according to the method outlined by Schertz (13). All extractions were made from leaf blade tissue of seedlings which had developed to the third leaf stage. Some difficulty was encountered in separating the carotin and xanthophyll until the method was modified to include further extracting with methyl alcohol and petroleum ether after the original separation of these pigments had been made. Quantitative determinations were made by means of a colorimeter, using malachite green, orange G, and martius yellow for standards, in the proportions suggested by Sprague (14).

Extractions were made in duplicate from seedlings grown at temperatures of 24° and 17°C. From four to six readings were made on the colorimeter for each extraction. It was difficult, however, to get these readings to check closely. The figures given represent the average of these readings and are to be considered as relative rather than absolute. The results are shown in Table 1.

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[3]Figures in parenthesis refer to "Literature Cited", p. 479.

TABLE I.—*Quantitative determinations of chlorophyll and carotinoid pigments in seedlings of* RYD_4 *and* GG_{26} *grown in the greenhouse during the winter.*

Pigment content (mgs) in 10 grams fresh tissue					
Chlorophyll		Carotin		Xanthophyll	
RYD_4	GG_{26}	RYD_4	GG_{26}	RYD_4	GG_{26}
At 24°C					
29.2	15.4	0.4	0.3	0.5	0.4
28.3	16.6	0.4	0.2	0.4	0.5
At 17°C					
29.9	Trace	0.5	Trace	0.4	0.5
30.6	Trace	0.5	Trace	0.5	0.4

The most significant point brought out by these data is the close parallel between chlorophyll and carotin formation. The extractions of the pigments from the seedlings of GG_{26} grown at 17°C showed only a trace of green pigments and of carotin, whereas the xanthophyll content remained as high at 17° as at 24°C. It will also be noted that chlorophyll pigmentation and also carotin formation was less in GG_{26} at 24°C than in RYD_4. The chlorophyll and carotin content of seedlings of RYD_4 was approximately the same at 17° as at 24°C. It is suggested that the parallel relationship shown between chlorophyll and carotin formation may be due to both these pigments being dependent upon the reaction of the same gene or gene complex for their expression or due to different genes which react alike under these environmental conditions. There is also the possibility of a chemical relationship between the chlorophyll and carotin molecules or their precursors.

FIELD EXPERIMENTS ON RELATION OF TEMPERATURE TO CHLOROPHYLL FORMATION

Seedlings of GG_{26} grown in the field at low temperatures show the virescent character. This was shown by field experiments in the spring of 1932 and the fall of 1933. In the spring of 1932 a planting of several inbred lines of corn, including GG_{26} and RYD_4, was made on April 18, which is about 1 month earlier than the usual planting date at Madison. Both lines reached the third leaf stage about May 12. During this period from May 2 to May 12, the air temperature during the day ranged from 23° to 15° with an average temperature of 19.3°C. The night temperature ranged from 12° to 7° with an average temperature of 10.5°C. Growing under these conditions the seedlings of GG_{26} showed the same virescent character as they did in the greenhouse at a temperature range of 16° to 19°C, whereas the seedlings of RYD_4 remained green.

A planting of these seedlings was also made in the field on September 23, 1933, from freshly harvested seed. The plants emerged from the soil about October 2 and had reached the third leaf stage

by October 13 when they were frosted. During this period the air temperature during the day ranged from 21° to 10° with an average temperature of 16°C. The night temperature ranged from 12° to about —3° with an average temperature of 9.2°C. Here again the seedlings of GG_{26} were virescent while those of RYD_4 were green in color. It seems, then, from the behavior of these seedlings, both in the greenhouse and in the field, that temperature is probably the principal environmental factor associated with the expression of the genetic factor complex controlling chlorophyll formation. However, the effect of low light intensity and a shorter period of light exposure evidently modifies the response to temperature.

INHERITANCE OF THE VIRESCENT CHARACTER

These two inbreds and the F_1 and F_2 generations produced from crosses between these lines were grown together in the greenhouse during the months of December and January at a temperature range of 16° to 19°C. Under these conditions the seedlings of GG_{26} and RYD_4 were virescent and green, respectively, the F_1 plants were all green, and the F_2 generation segregated for the green and virescent characters. The segregation was not clear cut, however, as there was a gradation in seedling color from white to normal green. The majority of the seedlings, however, were either definitely green or definitely virescent with a relatively small number representing the intermediate type. These intermediate plants were placed with the green or virescent group according to which group they resembled most. From a total of 1,301 F_2 plants, there were 970 green seedlings and 331 virescent seedlings. This is a close fit to a 3 : 1 ratio and it is therefore considered that this virescent phenotype is probably inherited as a simple Mendelian recessive to normal green. It would be desirable, however, to carry some of this material to the 3rd and 4th generations and to do some back crossing in order to be sure of a correct genetic analysis.

When populations from reciprocal crosses between RYD_4 and GG_{26} were considered separately, there was a higher percentage of virescent seedlings in the cross GG_{26} X RYD_4 than in the reciprocal cross. This situation existed in each of four different series. The results are shown in Table 2.

TABLE 2.—*Numbers and percentages of green and virescent seedlings in F_2 populations of the cross RYD_4 x GG_{26} and the reciprocal cross grown in the greenhouse at a temperature of 16° to 19°C.*

Cross	Number of plants	Number green	Number virescent	Percentage virescent
RYD_4 x GG_{26}	613	500	113	18.4
GG_{26} x RYD_4	688	471	217	31.5
Totals	1,301	971	330	25.3

From the descriptions of virescent seedlings given by Lindstrom (10), Demerec (2), Carver (1), and Phipps (12), it appears that the

type of virescence shown by the seedlings of GG_{26} most nearly corresponds to the virescent type 2 described by Demerec. The virescent seedlings also resemble the description of virescent 19 given by Phipps.

ENDOSPERM UTILIZATION AND TOP GROWTH

During the early seedling stages of development, corn plants are dependent largely on their endosperm reserves for respiration and growth. A rapid utilization of these materials necessitates an early establishment of an efficient photosynthetic activity on the part of the plant. Any condition which materially influences the establishment of this photosynthetic activity will generally influence the total amount and quality of plant tissues produced.

In this phase of the study an attempt has been made to determine the comparative rate of endosperm utilization and the amount of top growth produced during the seedling stages of RYD_4 and GG_{26}. Naturally, various factors of the environment enter into such a study. In these studies temperature has been the changing factor, other conditions having been kept as nearly constant as possible.

Plants were grown and harvested at successive growth stages at constant and at changing temperatures. The first series was removed from the soil at the time the first leaf had just broken through the coleoptile, the second series when the first leaf was completely unfolded and the second leaf was just beginning to unfold, the third series when the first and second leaves were unfolded and the third leaf just beginning to show at the top of the plant, and the fourth series when the first three leaves were unfolded. These growth stages were designated as the coleoptile, first leaf, second leaf, and third leaf stages of development, respectively. Other seedlings were grown to the third leaf stage at a temperature of 24°C then shifted to a temperature of 17°C for 4 and 8 days before being harvested.

Weights of tops and kernel remains were taken after the seedlings had been removed from the soil, washed with water, and the tops separated from the kernel by cutting them off at the cotyledonary node. Dry weights were taken after the plants had come to constant weight in an oven held at 100° to 105°C.

The amount of endosperm utilized by the plants was determined by subtracting the dry weight of the kernel remains from the calculated dry weight of the original kernel. From these figures the percentage decrease in weight of kernels was determined.

ENDOSPERM UTILIZATION AND TOP GROWTH OF SEEDLINGS GROWN AT CONSTANT TEMPERATURES

The results obtained on endosperm utilization and top growth of seedlings grown at constant temperatures are shown in Figs. 1 and 2. The data were obtained on populations of between 400 and 500 plants for each stage of development, represented by four different series.

The results (Fig. 1) show that at a temperature of 24°C the amount of top growth produced is the same for the two inbreds at every stage of development, whereas endosperm utilization is greater for GG_{26} at every stage of development, except at the coleoptile stage. The difference shown at the coleoptile stage is due to a more rapid germination of RYD_4. It is of interest to note further that seedlings of GG_{26}

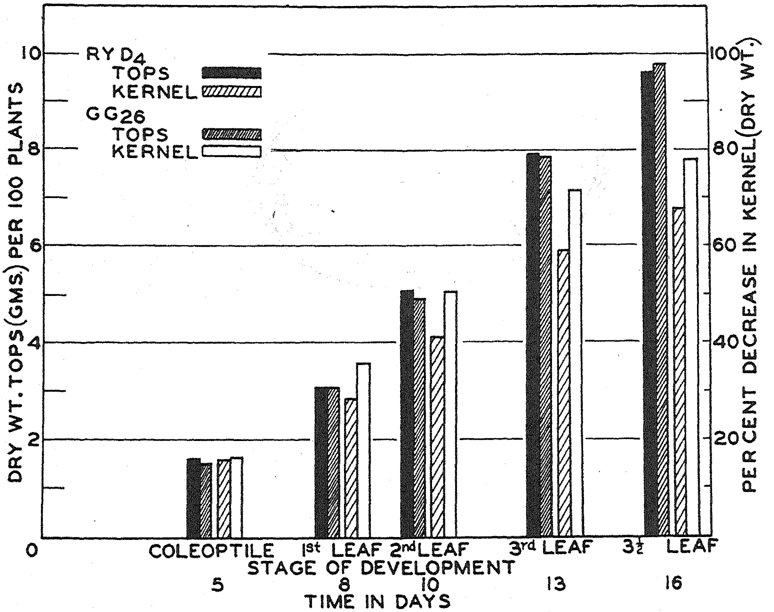

FIG. 1.—Top growth produced and endosperm utilized by seedlings of RYD_4 and GG_{26} grown in the greenhouse at 24°C.

have used practically all their reserves when they have reached the third leaf stage of development (the endosperm represents about 75 to 80% of the total corn kernel), whereas the seedlings of RYD_4 still have a considerable amount of reserve materials left in the kernel.

At a temperature of 17°C (Fig. 2) there is a greater amount of top growth produced by seedlings of RYD_4 than by seedlings of GG_{26}. This difference is small for the first three growth stages and is probably due to the early advantage gained by a more rapid germination of the RYD_4 seed. The increased difference in amount of top growth produced by RYD_4 over that produced by GG_{26} at the third leaf stage is due to a depletion of endosperm reserves in GG_{26} as the seedlings have developed no chlorophyll and are unable to synthesize additional materials for respiration and growth. The rate of top growth for the two inbreds is essentially the same, however, as long as endosperm reserves are available.

The results obtained at 17° also show a greater utilization of endosperm reserves by GG_{26} for the three later stages of development and a greater utilization by seedlings of RYD_4 at the coleoptile stage of

development. Here, as in the case of top growth, the difference at the coleoptile stage of development is due to a more rapid germination in RYD_4 than in GG_{26}. After germination is once started, however, endosperm utilization is considerably faster in GG_{26} than in RYD_4.

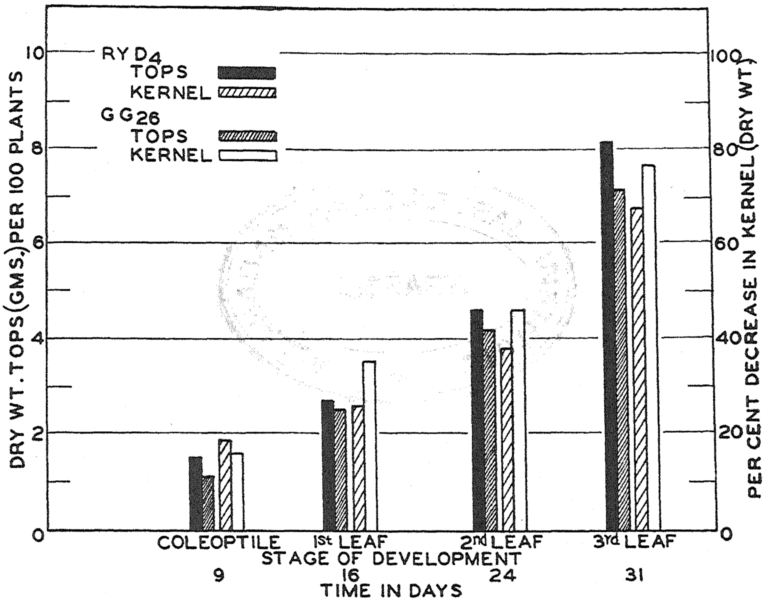

FIG. 2.—Top growth produced and endosperm utilized by seedlings of RYD_4 and GG_{26} grown in the greenhouse at 17°C.

ENDOSPERM UTILIZATION AND TOP GROWTH PRODUCED BY SEEDLINGS GROWN TO THIRD LEAF STAGE AT 24°C THEN SHIFTED TO A LOWER TEMPERATURE

The previous experiments have shown that there is a considerable difference in the amount of endosperm utilized by seedlings of RYD_4 and GG_{26} when grown at either a high or a low temperature. There is, however, practically no difference in the amount of top growth produced at these temperatures during the early seedling stages of development before the endosperm reserves have been depleted. What would be the effect on the growth of these seedlings if they should be subjected to low temperatures about the time the seedlings had reached the third leaf stage of development? The experiments described below represent an effort to answer this question.

Seedlings were grown to the third leaf stage at a temperature of 24° C then shifted to a temperature of 17°C. Data were taken on top growth and endosperm utilization on half the plants in each lot 4 and 8 days after being shifted to the lower temperature. The most advanced stage of development reached by any of these seedlings after being shifted to the lower temperature was the 3½-leaf stage;

therefore, a similar lot of seedlings was grown to the 3½-leaf stage at a temperature of 24°C to serve as a comparison. The results are shown in Fig. 3.

The data show that at the lower temperature there is considerable difference in the amount of top growth produced and endosperm utilized by the two inbreds. The seedlings of RYD_4 continued to grow

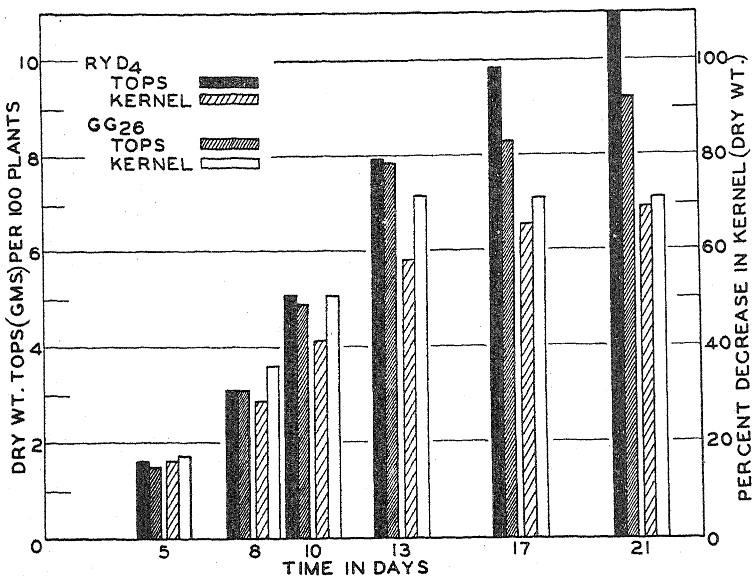

FIG. 3.—Top growth produced and endosperm utilized by seedlings of RYD_4 and GG_{26} grown to third leaf stage (13 days) at 24° C then shifted to 17° C for a period of 4 and 8 days before being harvested.

rather rapidly, whereas the seedlings of GG_{26} produced very little additional top growth after they were shifted to the lower temperature. There was also considerably more endosperm utilized by RYD_4 than by GG_{26}. This, however, was because the endosperm reserves of GG_{26} had been largely utilized by the time the plants had reached the third leaf stage of development and they had no additional reserves from which to draw.

RESISTANCE TO SEEDLING BLIGHT

As pointed out earlier in this paper, there is a marked difference in the ability of these seedlings to develop chlorophyll at a temperature range of 16° to 19°C. Such a contrasting difference indicates a marked difference in the metabolic balance within the young seedlings of these two inbreds. Dickson (3) and Dickson and Holbert (5) have shown that a difference in the metabolic balance within the seedlings of inbred lines of corn is manifest by their resistance or susceptibility to the seedling blight organism *Gibberella saubinetii* (Mont.) Sacc., and that resistance or susceptibility is conditioned principally by the effect of environment on the host rather than on the parasite. It

seemed reasonable, therefore, to test the susceptibility of inbreds RYD_4 and GG_{26} to *G. saubinetii* as an indication of the balance of metabolism within these seedlings. Such a test should indicate to what extent this inability to form chlorophyll at low temperatures is accompanied by a type of metabolism within the plant which influences the degree of resistance or susceptibility to this seedling blight organism.

The experiments on seedling blight were conducted in the greenhouse during the winter. The seedlings were grown in the greenhouse bench in a sandy loam soil at a room temperature of 17°C and a soil temperature of 16°C. Inoculations were made by placing the kernels in a conidial suspension of *G. saubinetii* for 5 to 10 minutes just previous to planting.

The plants were removed from the soil when they had developed to the third leaf stage, washed, and their resistant index calculated on the basis of 0 to 10; 0 representing complete killing and 10 representing freedom from disease.

The results from these inoculations showed a marked difference in the resistance of these two inbreds to the seedling blight organism. The seedlings of GG_{26} were killed completely before the coleoptile and primary roots had elongated to the extent of an inch. The plants of this line which developed further and showed large lesions very probably escaped the disease in the earlier stages of development. In contrast, many of the seedlings of RYD_4 showed small restricted lesions at the point where the seminal roots had broken through the cortical tissue of the cotyledonary node but in most cases had advanced no further. This difference in the resistance to seedling blight is shown in Figs. 4 and 5.

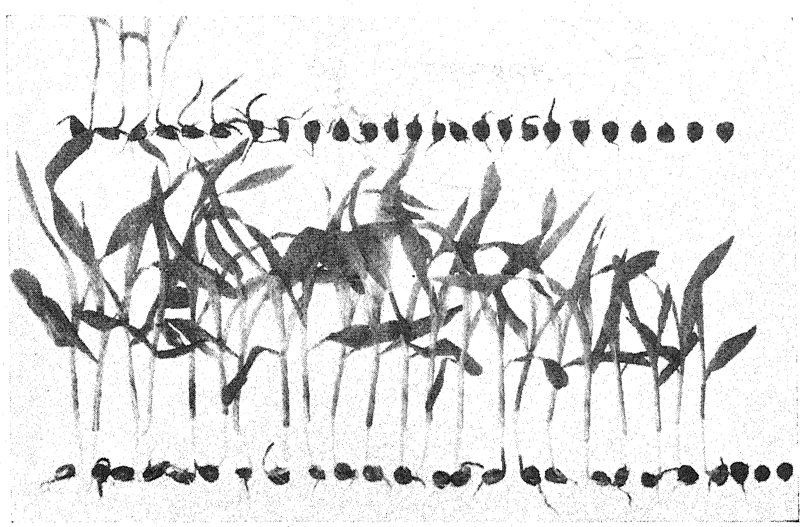

FIG. 4.—Difference in resistance of inbreds RYD_4 and GG_{26} to *G. saubinetii* at a soil temperature of 16°C. Top row GG_{26}, bottom row RYD_4.

Results obtained from inoculating the F_1 progenies showed that they were practically as resistant as the resistant parent. There was a strong indication, however, that the reciprocal crosses between these two inbreds do not behave alike when inoculated with the seedling blight organism. The progenies from the cross GG_{26} X RYD_4

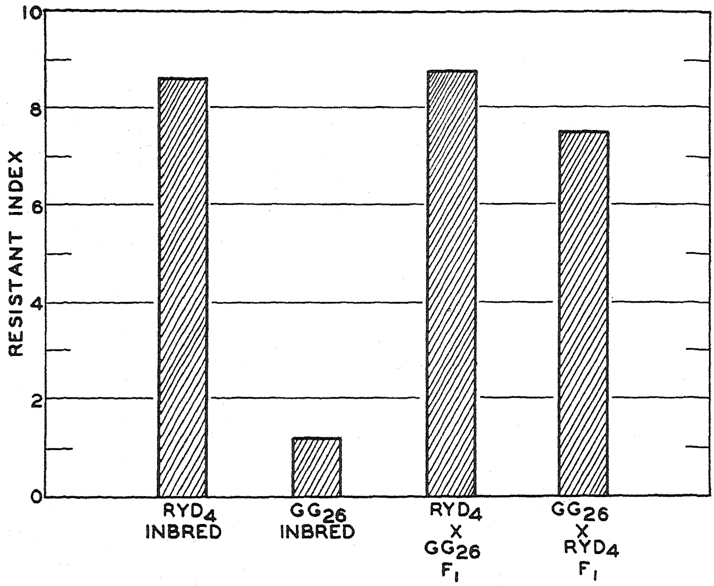

FIG. 5.—The resistant indices of the inbreds RYD_4 and GG_{26} and the F_1 generations from reciprocal crosses between these two inbreds.

were more susceptible than the progenies from the reciprocal cross. This difference, however, was not great enough to be detected by observations on the above-ground parts of the growing plants (Fig. 6).

RATE OF MATURITY

Under field conditions, these inbred lines of RYD_4 and GG_{26} show a considerable difference in the rate of seed maturation. When self-pollinations are made on the same date, plants of RYD_4 mature their seed about 10 days ahead of GG_{26}. This difference in rate of kernel development is evident within a few days following pollination. Such a difference in the rate of kernel maturation may have an important bearing on the factors conditioning the general metabolic balance within these young seedlings.

DISCUSSION

A consideration of the various experiments show that these lines of corn differ in their ability to develop at low temperatures. These two inbreds perhaps show a maximum of contrast in this respect. RYD_4 represents the seedling type which, when grown at low temperatures, is able to synthesize chlorophyll, make an efficient use of

the endosperm reserves, and develop plant tissues which resist the attack of the seedling blight organism. On the other hand, GG_{26} represents a seedling type which is unable to synthesize chlorophyll, makes an inefficient use of its endosperm reserves, and develops plant tissues which are susceptible to the seedling blight organism.

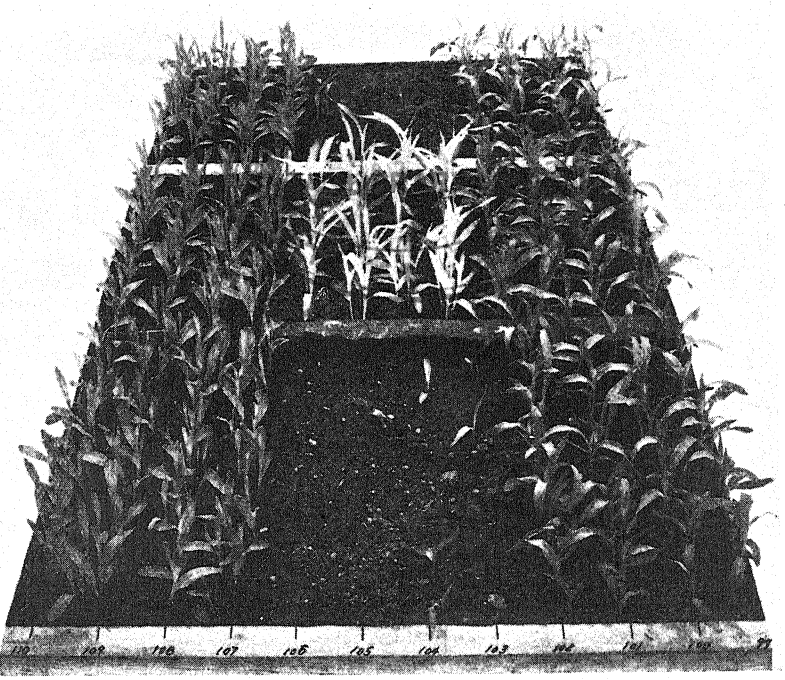

FIG. 6.—The difference in resistance to *G. saubinetii* of inbreds RYD_4 and GG_{26} and the F_1 progenies produced from crosses between these inbreds. Plants were grown at a soil temperature of 16°C. Rows 99–102 RYD_4; rows 103–106 GG_{26}; rows 107–108 RYD_4 x GG_{26}; rows 109–110 GG_{26} x RYD_4. Center panel, check plants, seed not inoculated; near panel, seed inoculated; far panel, seed inoculated.

There is an inter-relationship between endosperm utilization, chlorophyll formation, and tissue development. For example, when no chlorophyll is synthesized, photosynthesis is impossible, endosperm reserves become depleted and the plants die, unless in the mean time conditions have become favorable for chlorophyll formation. On the other hand, when chlorophyll is synthesized the plants are able to maintain a balance between endosperm utilization and photosynthesis which enables them to continue their normal course of growth and tissue development.

The results also show that these seedlings differ in their metabolic balance when grown at a temperature of 16°C. Seedlings of RYD_4 maintain a well-balanced metabolism and produce plant tissues which

will resist the attack of the seedling blight organism, whereas GG_{26} maintains an unbalanced metabolism and develops tissues which are susceptible to the attack of the seedling blight organism.

The unbalanced metabolism which predisposes the plants to the attack of the seedling blight organism is not a direct result of the inability of these seedlings to synthesize chlorophyll at the lower temperatures. The young plants of GG_{26} are attacked and killed by the seedling blight organism before the seedlings have emerged from the soil. Therefore, the lack of ability to synthesize chlorophyll can have little to do with the conditioning of the susceptibility shown by these plants.

The susceptibility to seedling blight may be conditioned earlier than at the seedling stage of development. Hoppe and Holbert (9) have shown that inbreds which have an extended type of maturation in the fall are more susceptible to seedling blight than those which mature earlier. This is in good agreement with field observations on inbreds RYD_4 and GG_{26}. Plants of RYD_4 mature kernels more rapidly in the fall than GG_{26} and are also more resistant to *Gibberella* seedling blight in the seedling stage of development.

The more rapid kernel development by RYD_4, is evident long before the corn is mature in the fall. Within 4 or 5 days following pollination, endosperm development is apparent in RYD_4, whereas in GG_{26} about a week elapses after pollination before it is possible to determine whether or not pollination has been effective. From this standpoint, however, it is assumed that approximately the same length of time elapses between pollination and fertilization in these two inbreds. If a difference in the rate and type of maturation of the kernel influences the degree of resistance which will be manifest by the seedling plant, this would explain, in part at least, the difference in in the degree of resistance to seedling blight shown by the F_1 seedlings from reciprocal crosses between these two inbreds.

The results also show that resistance to seedling blight is dominant in this cross. The F_1 plants showed practically the same degree of resistance as the resistant parent. There is a possibility, however, that heterosis enables the F_1 plants to outgrow the parasite. This is unlikely, however, as there were restricted lesions on the F_1 plants at the point of emergence of the seminal roots. This would indicate that they were resisting the parasite rather than outgrowing it.

SUMMARY

This paper deals with a study of the comparative ability of seedlings of two inbred lines of corn to grow at low temperatures and maintain a well-balanced type of metabolism during the early stages of seedling development.

The studies were limited to two contrasting inbreds known as RYD_4 and GG_{26} and subsequent progenies produced from crosses between these two inbreds. When grown in the greenhouse during the winter at a temperature range of 16° to 19°C, the seedlings of RYD_4 were a normal green color, whereas the seedlings of GG_{26} were typically virescent, being almost devoid of chlorophyll. Both inbreds were green when grown at a temperature of 24°C.

This virescent character is probably inherited as a simple recessive to normal green.

Extraction of the chlorophyll and carotinoid pigments showed that in the seedlings of GG_{26} carotin was formed only when chlorophyll formation occurred. Xanthophyll, however, was formed in the absence of the chlorophyll pigments.

Endosperm utilization was more rapid in seedlings of GG_{26} than in seedlings of RYD_4 when grown at a temperature fo 17° or 24°C. The endosperm reserves of GG_{26} were practically exhausted when the seedlings had developed to the third leaf stage, whereas seedlings of RYD_4 had considerable reserve materials left at this stage of development.

The amount of top growth produced by the seedlings of these two inbreds was essentially the same when grown at 17° and 24°C. There was a greater amount of top growth produced by inbred RYD_4, however, when the plants were grown to the third leaf stage at a temperature of 24°C then shifted to a temperature of 17°C for a period of 4 and 8 days.

At a soil temperature of 16°C the seedlings of RYD_4 were highly resistant to *Gibberella* seedling blight, whereas seedlings of GG_{26} were very susceptible. The F_1 progenies showed about the same degree of resistance as the resistant parent. Seedlings of the cross $RYD_4 \times GG_{26}$ were more resistant than the F_1 progenies of the reciprocal cross.

LITERATURE CITED

1. CARVER, W. A. A genetic study of certain chlorophyll deficiencies in maize. Genetics, 12: 415–440. 1927.
2. DEMEREC, M. Genetic relations of five factor pairs for virescent seedlings in maize. Cornell Univ. Agr. Exp. Sta. Mem. 84: 1–38. 1924.
3. DICKSON, J. G. Influence of soil temperature and moisture on the development of the seedling blight of wheat and corn caused by *Gibberella saubinetii*. Jour. Agr. Res., 23: 837–870. 1923.
4. ————, ECKERSON, S. H., and LINK, K. P. Nature of resistance to seedling blight of cereals. Proc. Nat. Acad. Sci., 9: 434–439. 1923.
5. ————, and HOLBERT, J. R. The influence of temperature upon the metabolism and expression of disease resistance in selfed lines of corn. Jour. Amer. Soc. Agron., 18: 314–322. 1926.
6. EMERSON, R. A. The genetic relations of plant colors in maize. Cornell Univ. Agr. Exp. Sta. Mem. 39: 1–156. 1921.
7. EULER, H. V., and HELLSTRÖM, H. Über die Bildung von Xanthophyll, Carotin und Chlorophyll in belichteten und unbelichteten Gerstenkeimlingen. Zeit. für Phys. Chem., 183: 177–183. 1929.
8. GUTHRIE, J. D. Effect of environmental conditions on the chloroplast pigments. Amer. Jour. Bot., 16: 716–746. 1929.
9. HOPPE, P. E., and HOLBERT, J. R. Unpublished manuscript on "The effect of immaturity upon the expression of resistance to *Gibberella* seedling blight in corn".
10. LINDSTROM, E. W. Chlorophyll inheritance in maize. Cornell Univ. Agr. Exp. Sta. Mem., 13: 7–68. 1918.
11. OSERKOWSKY, J. Relation between the green and the yellow pigments in chlorotic leaves. Plant Phys., 7: 711–716. 1932.
12. PHIPPS, I. F. Inheritance and linkage relations of virescent seedlings in maize. Cornell Univ. Agr. Exp. Sta. Mem. 125. 1929.
13. SCHERTZ, F. M. The extraction and separation of chlorophyll, (a and b) carotin and xanthophyll in fresh green leaves preliminary to quantitative determinations. Plant Phys., 3: 211–216. 1928.
14. SPRAGUE, H. B. A convenient method of measuring quantities of chloroplast pigments. Science, 67: 167–169. 1928.

ANALYSIS OF VARIANCE OF CORN YIELDS OBTAINED IN CROP ROTATION EXPERIMENTS[1]

R. J. GARBER AND T. C. MCILVAINE[2]

IN 1925 a crop rotation experiment involving 270 plats was established at the Lakin Experiment Farm near Point Pleasant, W. Va. The general plan of procedure and a diagram of the location of the plats have been published (2),[3] hence need not be repeated here. The purpose of this paper is to present the results of an analysis of variance of the corn yields obtained during 9 years, 1925 to 1933, inclusive, in three 4-year, three 3-year, and three 2-year rotations. Each rotation contained corn grown for grain as one of the crops. Each crop in the rotations was grown each year on duplicated plats of approximately 1/51 acre net in both the limed and unlimed series. On the former series finely ground limestone was applied as needed to maintain the pH level at approximately 7. All plats received annually about 200 pounds of superphosphate. The soil was mapped as Wheeling fine sandy loam by the Bureau of Chemistry and Soils of the U. S. Dept. of Agriculture (5).

Unfortunately, the plats in this experiment were not distributed in randomized blocks, but it was thought that the systematic distribution used did give at least a fairly adequate systematic sampling of the variability in the field. In this connection the juxtaposition of the plats compared should be taken into consideration. The location of the plats may be ascertained from Table 1 and from a diagram in the previous publication (2, p. 256).

TABLE 1.—*The number labels of the plats involved in the unlimed series in certain rotation experiments at the Lakin Experiment Farm, Lakin, W. Va.*

Plat numbers	Block
4-year rotations:	
1–3, 13–15, 25–27, 33–35	I
111–113, 123–125, 135–137, 143–145	II
3-year rotations:	
6–8, 18–20, 30–32	I
116–118, 128–130, 140–142	II
2-year rotations:	
9–11, 21–23	I
119–121, 131–133	II

The number labels shown in Table 1 are for the unlimed series. The corresponding limed plats carry numbers that are greater by 50. For example, plats 1 and 51 which occur end to end in block 1 are occupied by the same crop of a given rotation, but plat 51 receives lime and plat 1 does not. A similar differential treatment distinguishes plats 2 and

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[2]Agronomist and Assistant Agronomist, respectively.

[3]Reference by number is to "Literature Cited," p. 485.

52, 3 and 53, 13 and 63, etc. Consecutively numbered plats in the field are in contiguous (side by side) positions. All the plats and treatments in block I are duplicated in block II. A total of 108 different plats were involved of which 36 were in corn each year.

Another criterion may be used as a measure of the adequacy of systematic sampling in this instance. It has been shown (3) that the yields obtained during the first 5 years of the rotation experiment were positively correlated with the yields of a uniformity crop of oats harvested previously. The question arises as to whether the systematic location of plats in blocks I and II truly represented the variance that existed in these blocks. Using Table 1 to locate the plats and the yields (2) of the uniformity crop of oats, an analysis of the variance in each block may be made by means of the methods developed by Fisher (1). The results of such an analysis are shown in Table 2.

TABLE 2.—*Analysis of variance of yields of a uniformity crop of oats grown in 1923 on certain plats at the Lakin Experiment Farm, Lakin, W. Va.*

Block	Variation	Degree of freedom	Sum of squares	Mean squares	½ log$_e$ of mean square	Z*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Between groups...	2	185,134	92,567	5.7179	
I	Within groups....	51	3,561,517	69,834	5.5769	0.1410
	Total............	53	3,746,651	70,692	5.5831	
	Between groups...	2	16,656	8,328	4.5137	
II	Within groups....	51	2,680,316	52,555	5.4348	0.9211
	Total...........	53	2,696,972	50,886	5.4187	

*A Z value of 0.5738 is necessary where $n_1 = 2$ and $n_2 = 60$ for a 5% level of significance, and where $n_1 = 51$ and $n_2 = 2$ a Z value slightly in excess of 1.4840 is necessary for a similar level of significance according to Fisher's (1) 5% table.

The yields of the uniformity oats obtained from the 12 plats in block I now occupied by the 2-year rotations were placed in one group; similarly, those from the 18 plats now in the 3-year rotations in a second group; and those from the 24 plats now in the 4-year rotations in a remaining group. The same procedure was followed with the uniformity yields obtained in block II.

It is apparent from Table 2, particularly from the Z values recorded in column 7, that the variance between groups and within groups is not significantly different, either among the plats in block I or among those in block II. Likewise, it may readily be determined that neither the variance between groups nor that within groups differs significantly from the total variance in a particular block. This is interpreted to mean that insofar as the uniformity crop is concerned the systematic arrangement of the plats in a certain block with respect to 2-, 3-, and 4-year rotations gave a representative sample of the total variance in that block.

CORN YIELDS

The yields of corn in the rotation experiments were determined and were expressed on the basis of air-dry shelled corn. The individual

plat yields are not recorded here but are available on mineographed sheets to anyone interested. The average yield of corn in block I for the 9-year period was approximately 3.1 bushels more than in block II.

ANALYSIS OF VARIANCE

In Table 3 are recorded the results of analyzing the variance in the 324 corn yields. In column 1 the sources of variation are shown and in column 2 the degrees of freedom. There is one degree of freedom for blocks since the experiment was carried on in duplicate. Nine different rotations are involved on both limed and unlimed plats and therefore there are eight degrees of freedom for rotations and one for lime treatment. Similarly, since the work was carried on for 9 years, there are eight degrees of freedom for years. The degrees of freedom for the several interactions may be determined by simple multiplication.

TABLE 3.—*Analysis of variance of yields of corn obtained in certain rotation experiments during 9 years at the Lakin Experiment Farm, Lakin, W. Va.*

Variation due to	Degree of freedom	Sum of squares	Mean squares	½ loge of mean square	Z
(1)	(2)	(3)	(4)	(5)	(6)
Blocks	1	820.82	820.820	3.3552	1.4416*
Rotations	8	21,830.00	2,728.750	3.9558	2.0422*
Lime	1	1,801.06	1,801.060	3.7481	1.8345*
Years	8	24,281.41	3,035.176	4.0090	2.0954*
Blocks x years	8	521.32	65.165	2.0885	0.1749
Rotations x years	64	14,924.91	233.202	2.7260	0.8124*
Rotations x lime	8	571.11	71.389	2.1341	0.2205
Lime x years	8	603.03	75.379	2.1612	0.2476
Years x rotations x lime	64	2,150.99	33.609	1.7574	—0.1562
Blocks x rotations	8	total for error			
Blocks x lime	1				
Blocks x years x rotations	64				
Blocks x years x lime	8				
Blocks x rotations x lime	8				
Blocks x years x rotations x lime	64				
Error	153	7,027.75	45.933	1.9136	
Grand total	323	74,532.40			

*Significant according to Fisher's 1% table.

The interactions making up the estimate of error are delineated separately, but it is not necessary to calculate separately their contribution to sum of squares (column 3) because their combined contribution is all that is of interest. In this experiment the two differentials introduced in the plan were rotations and lime treatment, and therefore it would seem that the various interactions between them, on the one hand, and the blocks, on the other, would constitute a legitimate estimate of error. The variance attributable to blocks and to interaction between blocks and years may be eliminated since the experimental differentials are balanced (or would be so theoretically if the arrangement had been randomized throughout) in these two

sources of variation. A total of 153 degrees of freedom is available on which to base the estimate of error.

In column 6, Table 3, are recorded the Z values which are the differences between ½ $\log_e$ of mean square (1.9136, column 5) of the error and that of each of the other sources of variation. The Z values that are starred are significant as determined from Fisher's (1) 1% table. It may be observed that the variation due to blocks, rotations, lime treatment, years, and the interaction between rotations and years are significant. The fact that the variation due to blocks is significant shows that a worthwhile reduction in the estimate of error has been made by design of the experiment. The rotations, as well as the lime treatment, apparently are responsible for significant variations in the corn yields. The seasonal effect of the different years on the yield of corn is likewise significant. The fact that the interaction between rotations and years is of importance shows that the relative influence of the rotations on corn yields is not the same in the different seasons. One might wish to analyze this differential response further. This could be done in a manner similar to that suggested recently by Immer, Hayes, and Powers (4).

The other sources of variation are not significant as determined from the Z values and Fisher's 1% table. The lime treatments gave about the same relative response in the different rotations as measured by the corn yields. Similarly, the limed and unlimed plats maintained their relative corn yields throughout the duration of this experiment. In view of the last two statements, it is not surprising to find no significant double interaction among years x rotations x lime.

If it were desired to examine the significance of a difference between the average or the total yields of some particular plats, the standard error might be used. For this purpose the standard error of a single plat yield may be obtained by extracting the square root of the mean square (last mean entered in column 4) for error. This is found to be 6.777.

It will be recalled that the rotations involved in this analysis include three 4-year, three 3-year, and three 2-year rotations. Since a considerable part of the variation in the corn yields was contributed by them, it may be of interest to separate this variation into its two components, namely, that between groups of rotations based upon length of rotation and that between rotations of the same group. This has been done in Table 4.

TABLE 4.—*Analysis of variance of corn yields attributable to crop rotations.*

Variation	Degree of freedom	Sum of squares	Mean squares	½ $\log_e$ mean square	Z
(1)	(2)	(3)	(4)	(5)	(6)
Between rotations in general..	8	21,830.00	2,728.750	3.9558	—
Between rotation groups (2-, 3-, and 4-year rotations)...	2	20,612.51	10,306.255	4.6203	—
Between rotations within groups..................	6	1,217.49	202.915	2.6564	1.9639

Table 4 shows that the variation from group to group among the 2-, 3-, and 4-year rotations is greater than the variation among the rotations within the same group as measured by the corn yields. The Z value (column 6) obtained by taking the difference of ½ $\log_e$ of mean squares between these two sources of variation is 1.9639, a significant number. Moreover, the variation contributed by groups as well as that contributed by rotations within groups is significant when compared with that due to error (Table 3). For this comparison, the Z value for rotation groups was 2.7067 and that for rotations within the same group 0.7428.

CORRELATION BETWEEN THE YIELDS OF A UNIFORMITY CROP AND CORN

Before the rotation experiments were begun in 1925 the entire area involved had been previously cropped to oats in 1923 and to wheat in 1924. The correlations between the yields of these uniformity crops and the yields obtained during the first 5 years of the rotation experiments have been reported. In Table 5 the correlations are shown between the yields of corn in the rotations under discussion in the present paper and the yields of the uniformity oat crop on the same plats.

TABLE 5.—*Correlations between the yields per plat of a uniformity oat crop grown in 1923 and the yields on the same plats of corn in the rotation experiments during subsequent years at the Lakin Experiment Farm, Lakin, W. Va.*

Year of corn crop	n	r*
(1)	(2)	(3)
1925	36	0.370
1926	36	0.525
1927	36	0.559
1928	36	0.161
1929	36	0.482
1930	36	0.280
1931	36	0.036
1932	36	0.521
1933	36	0.016
1925–29	180	0.391
1930–33	144	0.290
1925–33	324	0.346

*According to Fisher's (1) V. A. table, an r value of at least 0.330 is necessary where n = 36 for odds of 19 to 1 (P = .05) for significance.

All the correlations in column 3 of Table 5 are positive although four of the nine interannual correlations are not statistically significant. This perhaps is not surprising in view of the fact that n in these studies was only 36. In 1930, the year of the drought, the rainfall at Lakin was much below the average during the growing season. For this reason the yields of corn from 1925 to 1929 and from 1930 to 1933, inclusive, were correlated separately with the yields of the uniformity crop. The correlation for the first period is 0.391 and for the second is 0.290, both being significant. The correlation coefficient between all the corn yields and the corresponding yields of the uniformity crop is 0.346.

The correlations presented in Table 5 show very definitely that an appreciable amount of the total variation in the corn yields may be accounted for by the different levels of natural productivity that existed among the plats when the rotation experiments were begun, as measured by a uniformity crop. In view of this fact the experimental error might be reduced still further by analyzing the covariance between the yields of the uniformity crop and the corn yields obtained subsequently.

SUMMARY

A brief discussion is presented of the effectiveness of the "analysis of variance" method as developed by Fisher (1) in analyzing certain corn yields obtained over a period of 9 years in a rotation experiment at Lakin, W. Va. An example is given of a systematic arrangement of plats that proved to be truly representative.

LITERATURE CITED

1. FISHER, R. A. Statistical Methods of Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1932.
2. GARBER, R. J., MCILVAINE, T. C., and HOOVER, M. M. A study of soil heterogeneity in experimental plots. Jour. Agr. Res., 33: 255–268. 1926.
3. ——————, and HOOVER, M. M. Persistence of soil differences with respect to productivity. Jour. Amer. Soc. Agron., 22: 883–890. 1930.
4. IMMER, F. R., HAYES, H. K., and POWERS, LEROY. Statistical determination of barley varietal adaptation. Jour. Amer. Soc. Agron., 26: 403–419. 1934.
5. LATIMER, W. J., and MOONEY, C. N. Soil survey of the Point Pleasant Area. West Virginia, U. S. D. A., Bur. Soils Field Oper. 1910, Rpt., 14: 1077–1122. 1912.

DEFOLIATION EXPERIMENTS WITH KAOLIANG (*ANDROPOGAN SORGHUM*)[1]

H. W. LI AND T. N. LIU[2]

KAOLIANG is one of the most important food crops in North China. Farmers of that region have a practice of removing all the leaves except the top few at the time when the kernels are about in the dough stage. On account of lack of fuel and the deficiency of forage, the leaves thus obtained are used to advantage. Besides, the farmers claim that by means of defoliation maturity can be hastened to some extent. It is obvious that the leaves are vital for the plant to manufacture its food. When the plant is made destitute of its food factories, its yield of grain, which is the ultimate aim for growing the crop, naturally must be affected. The present experiments were planned to determine the amount of reduction in yield due to defoliation, and the time at which defoliation can be done with the least effect on the yield of the plant.

MATERIAL AND METHODS

The land on which this experiment was carried out was very level and was sandy loam in composition for the top 3 feet. This field had been sown to uniform crops for several previous cropping seasons. The rows were 45 feet long and 2 feet apart. An inbred stock of seed was used to insure uniformity. Hill planting was resorted to, with eight seeds planted in each hill. The distance between the hills was 1½ feet.

Planting was done on April 14. When the seedlings were about 3 inches high, each hill was thinned to one plant. Any missing hills were promptly taken care of by transplanting. Thus, an almost perfect stand was obtained. There were altogether 270 rows in the experiment and these were divided into nine different treatments with 10 replications for each. (Each treatment had three rows to form one plat.) The plats were laid out in a systematic manner. For every other two treatment plats there was an untreated check plat. Thus, in the whole experiment, there were six different treatment plats and three check plats. Defoliation was done by holding the leaf blade and pulling it off with a snap, leaving only the part that consists of the leaf sheath on the stalk. The plats of this experiment were harvested on August 11. Apparently there was no clear difference in the degree of maturity.

ANALYSIS OF EXPERIMENTAL DATA

Table 1 gives the yield of the individual plats (average of three rows) in the 10 replications for the different kinds of treatments.

From Table 1 it will be seen that the yields of the check plats are very uniform. In order to show the significance of the results obtained (Table 2), Fisher's method for the analysis of variance is used (1).[3]

[1]Contribution from the College of Agriculture, Honan University, Kaifeng, Honan, China. Received for publication March 23, 1935.

[2]Professor and Associate in Plant Breeding, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 491.

TABLE 1.—*Yield of the 90 plats of kaoliang in grams.*

Treatment*	Blocks†										
	1	2	3	4	5	6	7	8	9	10	Total
A	739	895	928	936	769	840	1,075	1,089	970	885	9,126
B	1,040	980	1,081	1,020	1,020	1,015	1,163	1,230	1,159	1,010	10,718
Ck_1	1,195	1,220	1,118	1,061	1,189	1,318	1,369	1,325	1,202	1,121	12,118
C	1,093	1,039	1,142	1,195	1,323	1,330	1,205	1,319	1,266	1,189	12,101
D	298	381	390	307	256	373	307	386	322	339	3,359
Ck_2	1,200	1,085	1,108	1,235	1,217	1,259	1,319	1,179	1,216	1,140	11,958
E	924	874	932	776	872	923	1,045	932	982	629	8,889
F	1,256	1,199	949	1,286	1,120	1,189	1,288	1,150	1,148	1,004	11,589
Ck_3	1,160	1,131	1,158	1,243	910	1,428	1,291	1,339	1,320	1,170	12,150
Total	8,905	8,804	8,806	9,059	8,676	9,675	10,062	9,949	9,585	8,487	92,008

*A = Starting July 5, two leaves were removed every other 5 days (starting from the bottom) until all the leaves were removed.
B = On August 1, all leaves removed. Kernels were about in dough stage.
C = Same as B, but three leaves on top left, as commonly done by farmers.
D = When plants bloomed (¾ of the head), all leaves removed.
E = When the kernels of each plant reached the milk stage, all leaves removed.
F = The leaves removed as the kernels of each plant reached the dough stage.
Ck = Untreated plats.

†Three rows each.

TABLE 2.—*Analysis of variance of data in Table 1.*

Variation due to	d. f.	Sum of squares	Mean square	F
Treatments	8	6,605,092.72	825,636.50	114.29
Blocks	9	320,079.08	35,564.34	———
Error	72	520,149.72	7,224.30	———
Total	89	7,445,321.52	———	———

From Table 2 the F (2) obtained is very large (for $n_1 = 8$, $n_2 = 70$, F at the 5% point is 2.07 and at the 1% point is 2.78). This means that the treatments are significantly different from one another. The standard error of the mean of the 10 plats is $\sqrt{\frac{7224.30}{10}}$. Any significant difference then should be $\sqrt{\frac{7224.30}{10}} \times \sqrt{2} \times 1.96 = 74.9$. A difference greater than 74.9 is considered significant. The comparison of the different treatments is shown in Table 3.

TABLE 3.—*Comparison of yield for different treatments.**

	B	C	D	E	F	Ck
A	−159.2	−297.5	+581.7	+28.7	−241.3	−289.9
B	———	−138.3	+735.9	+182.9	− 87.1	−135.7
C	———	———	+874.2	+321.2	+ 51.2	+ 21.6
D	———	———	———	−553.0	−823.0	−871.6
E	———	———	———	———	−270.0	−318.6
F	———	———	———	———	———	− 48.6

*Level of significance between two treatments $= \sqrt{\frac{7,224.30}{10}} \times \sqrt{2} \times 1.96 = 74.90$.

Taking the comparison of the different treatments with the average of the check plats first, it can be seen that, except for treatment C which has an insignificant increase of yield over the check, all others show a reduction in yield. All the reductions are statistically significant except that of treatment F. In treatment A, two leaves were taken off at 5-day intervals. This causes a gradual reduction of the leaf area. The significant reduction in yield as compared with the check should discourage farmers from starting defoliation too early even if there is an urgent need for the leaves. By removing all the leaves when the plants reach the dough stage, as in treatment B, a significant reduction in yield is again obtained. However, when all the leaves are removed except three at the top, as in treatment C, we find an insignificant increase over the check plat.

In order to show the critical stage at which the plants will either suffer or will not be affected by defoliation, individual plants were treated separately in the row. In treatment D defoliation was done when two-thirds of the heads reached the blooming stage, the plants being stripped of all the leaves. This is the most severe of all the treatments and resulted in the greatest reduction in yield. Defoliation at the time the plant reached the milk stage, as in treatment E, also resulted in a significant reduction in yield, but less than that in treatment D. By the time the plant has reached the dough stage, the leaves have performed their duty and defoliation will not affect the yield of the plant at all. Thus, treatment F showed a reduction in the yield as compared with the check, but it was statistically insignificant.

Since defoliation at the critical period results in the reduction of yield of kaoliang, it was desired to determine the cause of this reduction. Is it due to the reduction in the weight of the individual kernels or to the number of kernels per plant, or both? It is difficult to determine the exact number of kernels of an individual plant, but it is comparatively easy to find out the weight of the individual kernels. Table 4 gives the weight of 100 kernels in grams for the 90

TABLE 4.—*Weight of 100 kernels in grams for each plat of the different treatments.*

Treatments*	Blocks†										
	1	2	3	4	5	6	7	8	9	10	Total
A	1.35	1.66	1.67	1.65	1.54	1.65	1.88	1.88	1.61	1.55	16.44
B	1.69	1.96	1.89	1.91	1.87	1.91	1.90	1.96	1.90	1.90	18.89
Ck_1	1.96	2.14	2.01	1.99	2.00	2.13	2.06	2.02	2.12	1.96	20.39
C	1.89	2.06	2.02	2.01	1.99	2.14	1.97	1.97	2.04	1.98	20.07
D	1.08	1.21	1.09	1.03	1.08	1.19	1.07	1.24	1.16	1.09	11.24
Ck_2	2.01	2.07	2.10	2.02	2.03	2.04	2.01	2.11	2.08	1.96	20.43
E	1.67	1.53	1.58	1.58	1.50	1.53	1.70	1.69	1.69	1.54	16.01
F	2.00	1.81	1.96	1.90	2.13	2.05	2.07	1.96	2.05	1.89	19.82
CK_3	2.03	2.03	2.00	1.99	2.06	2.13	2.07	2.10	2.10	1.95	20.46
Total	15.68	16.47	16.32	16.08	16.20	16.77	16.73	16.93	16.75	15.82	163.75

*See Table 1 for plan of treatments.
†Three rows each.

plats with the samples taken at random, and Table 5 gives the analysis of variance of the data.

TABLE 5.—*Analysis of variance of data in Table 4.*

Variation due to	d. f.	Sum of squares	Mean square	F
Treatment	8	7.7881	0.9735	177
Blocks	9	0.1907	0.0212	—
Error	72	0.3945	0.0055	—
Total	89	8.3733		—

F in this case is also very large for the same n_1 and n_2 as in Table 2. Thus it shows clearly the significant difference between the treatments. The comparative difference between the treatments is shown in Table 6.

TABLE 6.—*Comparison of the weight of 100 kernels for different treatments.**

	B	C	D	E	F	Ck
A	−0.25	−0.37	0.52	0.04	−0.34	−0.40
B	—	−0.12	0.77	0.29	−0.09	−0.15
C	—	—	0.89	0.41	0.03	−0.03
D	—	—	—	−0.48	−0.86	−0.92
E	—	—	—	—	−0.38	−0.44
F	—	—	—	—	—	−0.06

*Level of significance between two different treatments $= \sqrt{\frac{0.0055}{10}} \times \sqrt{2} \times 1.96 = 0.651$

In general, the difference in the kernel weight for the different treatments agreed closely with that for the yield, except for treatment C. In this case it has an insignificant decrease of an increase.

In order to show the correlation of the two variables yield and weight of 100 kernels, an analysis of covariance was calculated and is shown in Table 7.

TABLE 7.—*Analysis of variance and covariance.*

Variation due to	d. f.	Sum of squares $(x)^2$ A	Sum of products (xy) B	Sum of squares $(y)^2$ C	$\frac{B^2}{A}$
Blocks	9	0.1907	196.870	320,079.08	—
Treatments	8	7.7881	7,106.612	6,605,092.72	—
Error	72	0.3945	110.528	520,149.72	30,966.89
Total	89	8.3733	7,414.010	7,445,321.52	—

The regression coefficient is $\frac{110.528}{0.3945}$. To test its significance we have $B^2/A = 30{,}966.89$. Hence an analysis of yield error is given in Table 8.

After an allowance is made for treatment and blocks, high yield is associated with heavier kernel weight, and *vice versa*. The value of r is .244 when n = 70; r at 5% level is .2319. The correlation coeffi-

TABLE 8.—*Analysis of yield error.*

	d. f.	Sum of squares	Mean square	F
Due to regression	1	30,966.89	30,966.890	4.49
Due to deviation	71	489,182.83	6,889.899	—
Total error	72	520,149.83	—	—

$N_1 = 1$ $F = 5\%$ 1%
$N_2 = 70$ 3.98 7.01

cient thus obtained is significant. We may conclude, therefore, that yield depends partly at least on the weight of individual kernels.

DISCUSSION

Some defoliation experiments have been conducted with *Zea Mays* by several American agronomists (3, 4), and the results obtained in the present experiment seem to agree closely with those for *Zea*, i. e., a reduction in yield and weight of kernels resulting from defoliation, according to the time defoliation is done. When the plant reaches the dough stage, the function of the leaves comes to an end. In fact, by this time, the leaves are turning yellow and are gradually drying up. Practically, most of the surplus food materials manufactured by the leaves have already been translocated to be stored up in the seeds. Stripping the leaves off at this stage would mean no loss to the plant at all so far as surplus food material is concerned. However, prior to this stage, reduction in the leaf surface would mean reduction in the weight of the grains produced and thus a reduction in yield. As it is the custom of farmers to defoliate only when the plants reach the dough stage or later, no reduction of yield is to be expected.

It seems that maturity is not hastened by defoliation, as can be observed superficially at least in this experiment. Nevertheless, when the leaves are removed from the lower part of plants in the field, free circulation of air can thus be obtained. This may mean a more rapid rate of transpiration and evaporation. Thus, the kernels of the plant might in this way give off water at a faster rate. However, a careful test must be carried out before any definite conclusion can be drawn.

SUMMARY

Kaoliang defoliation at the time when the plant reaches the dough stage results in insignificant reductions both in yield and in kernel weight.

Any defoliation done prior to this stage results in reduction both in yield and in kernel weight, the reduction being directly proportional to the earliness of defoliation.

The method used in stripping off the leaves from the kaoliang plant by farmers, i. e., at the dough stage and leaving a few leaves at the top of the plant, does not affect the yield and the kernel weight at all.

LITERATURE CITED

1. FISHER, R. A. Statistical Methods for Research Workers, Edinborough: Oliver and Boyd. Ed. 4. 1932.
2. SNEDECOR, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Ia.: College Press, 1931.
3. HUME, A. N., and FRANZKE, C. The effect of certain injuries to leaves of corn plants upon weights of grain produced. Jour. Amer. Soc. Agron., 21: 1156–64. 1929.
4. DUNGAN, G. H. Relation of blade injury to the yielding ability of corn plants. Jour. Amer. Soc. Agron., 22: 164–70. 1930.

INHERITANCE OF ANNUAL HABIT AND MODE OF POLLINATION IN AN ANNUAL WHITE SWEET CLOVER[1]

ALFRED E. CLARKE[2]

THROUGH the courtesy of Dr. L. W. Kephart, several species of *Melilotus* were obtained from the Bureau of Plant Industry, U. S. Dept. of Agriculture. One lot of seed was listed under the name *M. altissima* (Forage Plant Introduction No. 74479). When grown in the greenhouse it proved to be an annual white-flowered sweet clover. The plants appeared similar in morphological characters to those of Hubam sweet clover, an annual variety of *M. alba* generally thought to have arisen from the biennial type through mutation. According to Pieters and Kephart (13)[3], the importance of the annual variety was first recognized by Hughes, although it was probably observed by Tracy as early as 1898. In 1918, *M. alba* Desr. var. *annua* Coe was named and described by Coe (4). Smith (14) found that in crosses between Hubam and the biennial type the annual habit is inherited as a simple dominant.

INHERITANCE OF ANNUAL HABIT

The annual white-flowered strain obtained from the Bureau of Plant Industry was crossed with common biennial white sweet clover and two seeds were obtained. One produced an annual plant, like the female parent, and undoubtedly arose from accidental self-pollination. The other plant showed marked hybrid vigor since it was the largest sweet clover plant in the greenhouse, although grown to maturity in a small flower pot. In time of flowering it behaved as an annual but was later than the other annuals planted on the same date, probably on account of its greater vegetative growth. In the F_2, 202 annual and 60 biennial plants were obtained. This is a satisfactory fit to a 3:1 ratio, as shown in Table 1, and corresponds with the results obtained by Smith (14) in his study of the inheritance of the annual habit in Hubam sweet clover.

TABLE 1.—*Observed and expected frequencies in an F_2 population segregating for annual and biennial habit of growth.*

Cross	Observed		Expected (on 3:1 basis)		Dev. in numbers	P. E.	Dev. / P. E.
	Annual	Biennial	Annual	Biennial			
Annual x biennial	202	60	196.5	65.5	5.5	±4.73	1.2

[1]This paper represents a part of the work carried out by the author at the University of California while holding a National Research Council Fellowship in the Biological Sciences. Received for publication April 6, 1935.

[2]Associate in Genetics, University of California. The author wishes to express his indebtedness to Prof. E. B. Babcock for his kindly interest and helpful criticism.

[3]Numbers in parenthesis refer to "Literature Cited", p. 496.

Reciprocal crosses were made between this annual white strain and the Hubam variety to determine if both carried the same dominant factor for the annual habit. This proved to be so, since all of the F_1 plants were annual, and the F_2 progenies also bred true for the annual habit. Since the two strains were of different origin, it would seem that the mutation must have arisen independently in the two cases.

In a progeny of biennial spreading dwarf plants, a strain described in an earlier paper (2), a single plant was obtained which proved abnormal in its time of flowering. A few of its branches, arising from one portion of the crown, flowered much earlier than the others and were apparently annual. The remainder of the plant behaved as a biennial. The late-flowering part of this plant began blooming earlier than any of the other plants in the same progeny. A careful examination of its roots showed that only one plant was involved.

The plant was caged and the flowers tripped individually to insure self-pollination. Although the pollen grains appeared normal when viewed under the microscope, few seeds were obtained from the early-flowering portion of the plant and none from the late-flowering branches. No cytological irregularities were observed in root tip preparations from this plant. This result is not surprising since cytological studies reported in an earlier paper (3) failed to show any differences in chromosome morphology between the chromosome set of biennial *M. alba* and that of *M. alba annua*.

Seeds from the annual part of the plant produced five annual and three biennial plants. The number of plants in the population is too small to establish the mode of inheritance, but this probably represents a 3:1 ratio, with the annual character behaving as a dominant.

It seems probable that there occurred in this plant a dominant somatic mutation, making the annual portion heterozygous for time of flowering. It should be borne in mind that no dormant period is required in biennial sweet clover before flowering and that biennial plants frequently produce a few flowers during the first year's growth. In this genus, therefore, a change from the biennial to the annual habit is only a change in time of maturity. Nevertheless, these results do suggest the manner in which annual species or subspecies may sometimes be derived from biennial species.

INHERITANCE OF MODE OF POLLINATION

A knowledge of the mode of pollination of a species and whether or not it is self-sterile is important in genetical studies and also in practical plant breeding. Sweet clover species and strains differ markedly in the readiness with which they set seed after self-pollination, and there is considerable difference of opinion over the reason for such differences.

Müller (12) noted that in common yellow sweet clover, *M. officinalis*, the pistil is longer than the stamens, so that self-pollination is rendered unlikely. Darwin (5) reported that a plant of this species, when protected from insect visits produces few seeds while an unprotected plant produces many. Knuth (11) listed *M. officinalis* as

self-sterile. Kirchner (7) found that in common white sweet clover, *M. alba*, self-pollination occurs regularly. Both Kirk (8) and Elders (6) conclude that white sweet clover is highly self-fertile, while yellow sweet clover is either somewhat self-sterile or very sensitive to caging. Kirk and Stevenson (9, 10) have pointed out that in *M. alba* close proximity of stigmas and anthers seems to facilitate self-pollination, but this does not always hold in *M. officinalis*. The chief factor in natural self-pollination in *M. alba* seems to be the distribution of the pollen within the unopened flowers which in turn depends on the relative length of the stamens and style, the amount of pollen produced, and the size of the cavity in the upper part of the keel.

Recently, Brink (1) has shown that self-incompatibility in *M. officinalis* is caused by a reduced rate of germination of a plant's own pollen on its stigma and the slow growth of the pollen tubes under these conditions.

Ufer (15, 16) has listed some species which do not naturally self-pollinate and others in which good seed setting always accompanies natural self-pollination. With *M. altissimus*, *M. sulcatus*, *M. italicus*, and *M. albus annuus* the results vary between plants within the particular species. The results are much more uniform within single plant progenies than between unrelated plants.

The writer noted that some plants of the annual white strain, Forage Plant Introduction No. 74479, have pistils of the same length as the stamens, while in other plants the pistils are longer than the stamens. This suggests that differences in style length between individual plants may account, at least in part, for differences in seed-setting capacity between plants of this strain when grown in the greenhouse under cages to exclude insects and insure self-pollination. Some racemes were tripped, while others were left untripped as controls. The results obtained are shown in Table 2.

TABLE 2.—*Effect of artificially tripping blossoms in a strain of annual white sweet clover (F. P. I. No. 74479).*

	Pistil and stamens of the same length		Pistil longer than stamens	
	Untripped	Tripped	Untripped	Tripped
No. of plants	7	7	4	4
No. of flowers	3,267	3,334	2,274	1,566
No. of pods	1,335	2,023	321	656
Per cent pods	40.9±7.0	60.7±6.2	14.1±4.2	41.3±9.4
Odds that difference is significant, calculated from original data by Student's method	75.9 to 1		322 to 1	

Difference in percentage of pods obtained from untripped flowers with pistil and stamens of the same length, and from untripped flowers with pistil longer than the stamens	26.8 ± 8.2
Difference in percentage of pods obtained from tripped flowers with pistil and stamens of same length, and tripped flowers with pistil longer than the stamens	19.4 ± 11.3

When the pistil and stamens were of the same length, a higher percentage of pods was secured from tripped than from untripped

flowers, showing that tripping was effective in increasing the number of pods obtained. The increase was much more pronounced, however, when the pistil was longer than the stamens. This indicates that the relative length of pistil and stamens was an important factor in determining how much natural pollination took place. The importance of relative length of pistil and stamens is also shown by the greater number of pods obtained from untripped flowers with pistil and stamens of the same length. Tripped flowers with the pistil longer than the stamens set less seed than tripped flowers in which the male and female organs were of equal length, but the difference in percentage of pods obtained was only 1.8 times the probable error and need not be considered significant. In any event, a slightly reduced number of pods might result from pollen getting on the pistil in fewer cases when the pistil was longer, even though the flowers were tripped, and does not necessarily imply that plants of the latter type were less efficient seed producers if pollination was once effected. The data indicate that when the pistil and stamens are of equal length, natural self-pollination occurs fairly readily, but that there is very little natural self-pollination when the pistil is longer than the stamens, and relatively few pods are secured unless tripping is practiced.

When a plant with pistil and stamens of the same length was crossed with a plant in which the pistil was longer than the stamens, the F_1 plants were found to possess flowers with pistil and stamens of the same length. F_2 data, shown in Table 3, indicate that the long pistil is inherited as a simple Mendelian recessive.

TABLE 3.—*Observed and expected frequencies in F_2 families of a cross between annual white sweet clover plants (F. P. I. No. 74479) with pistil longer than stamens and with pistil the same length as stamens.*

Cross	Observed		Expected		Dev. in numbers	P. E.	Dev./P. E.
	Pistil same length	Pistil longer	Pistil same length	Pistil longer			
3 x 8—A	62	20	61.5	20.5	0.5	±2.64	Less than 1
3 x 8—B	67	21	66.0	22.0	1.0	±2.74	Less than 1
3 x 8—C	151	47	148.5	49.5	2.5	±4.11	Less than 1
Total	280	88	276.0	92.0	4.0	±5.60	Less than 1

SUMMARY

1. In crosses between an annual strain of white-flowered sweet clover and common biennial white sweet clover, the annual habit is dominant over the biennial and a 3:1 ratio is obtained in the F_2 generation.

2. Reciprocal crosses with Hubam sweet clover indicate that, although of different origin, the two annual strains possess the same dominant mutation for the annual habit.

3. A plant is described which was partially annual and partially biennial. This was apparently caused by a dominant somatic mutation, the annual portion being heterozygous for time of flowering.

4. Relative length of pistil and stamens was found to be correlated with the ease of self-pollination. When pistil and stamens are of the same length, self-pollination readily takes place, but when the pistil is longer than the stamens, there is very little self-pollination.

5. The type of flower in which the pistil is longer than the stamens is inherited as a simple recessive.

LITERATURE CITED

1. BRINK, R. A. Self-incompatibility in yellow sweet clover, *Melilotus officinalis*. Jour. Amer. Soc. Agron., 26: 307–312. 1934.
2. CLARKE, A. E. Inheritance of the dwarf branching habit in sweet clover. Sci. Agr., 11: 326–332. 1931.
3. ———. The number and morphology of chromosomes in the genus *Melilotus*. Univ. Calif. Pub., Bot., 17: 435–443. 1934.
4. COE, H. S. An annual variety of *Melilotus alba*. Jour. Amer. Soc. Agron., 9: 380–382. 1918.
5. DARWIN, C. The Effects of Cross and Self Fertilization in the Vegetable Kingdom. New York. 1885.
6. ELDERS, A. T. Some pollination and cytological studies of sweet clover. Sci. Agr., 6:360–365. 1926.
7. KIRCHNER, O. Ueber die Wirkung der Selbstbestäubung bei den Papilionaceen. Naturw. Ztschr. Land-u. Forstw. Jahr., 3 (1): 1–16; (2): 49–64; (3): 97–111. 1905.
8. KIRK, L. E. Self-pollination of sweet clover. Sci. Agr., 6: 109–112. 1925.
9. ———, and STEVENSON, T. M. Factors which influence spontaneous self-fertilization in sweet clover (*Melilotus*). Can. Jour. Res., 5: 313–326. 1931.
10. ———, ———. Spontaneous self-fertilization in relation to seed production in sweet clover (*Melilotus*). Can. Jour. Res., 5: 660–664. 1931.
11. KNUTH, P. Handbook of flower pollination. Trans. by J. R. A. Davis. Oxford. 3 vols. 1906–09.
12. MÜLLER, H. The fertilization of flowers. Trans. by D. A. Thompson. London. 1883.
13. PIETERS, A. J., and KEPHART, L. W. Annual white sweet clover and strains of the biennial form. U. S. D. A. Circ. 169. 1929.
14. SMITH, H. B. Annual versus biennial growth habit and its inheritance in *Melilotus alba*. Amer. Jour. Bot., 14: 129–146. 1927.
15. UFER, M. Untersuchungen über die Befruchtungsverhältnisse einiger Melilotusarten (Steinklee). Der Züchter, 2: 341–354. 1930.
16. ———. Weitere Untersuchungen über die Befruchtungs- und Kreuzungsverhältnisse einiger Melilotusarten (Steinklee). Der Züchter, 3: 353–360. 1931.

NOTES

AN INEXPENSIVE TYPE OF CONSTRUCTION FOR CONCRETE TANKS FOR SOIL INVESTIGATIONS

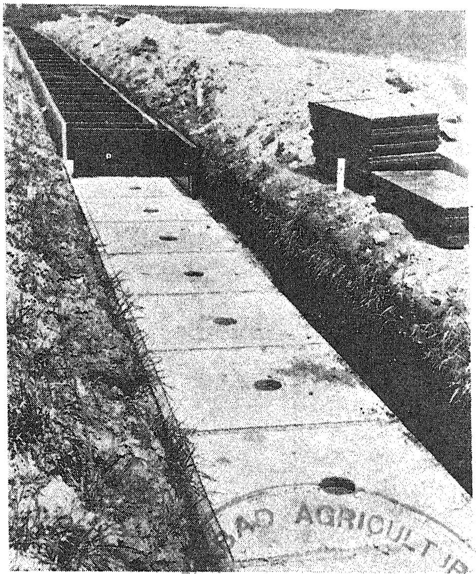

FIG. 1.—Showing method of construction of concrete tanks.

FOR use in soils investigations, 50 concrete frames were constructed in the spring of 1933 at Massachusetts State College. These have a concrete bottom, and each is provided with an individual drain (Fig. 1). Thus, each one is a potential lysimeter. At present every fifth frame is provided with means for collecting drainage water.

The inside measurements of the frames are 1 m x 1 m x 0.5 m. The outer walls are 5 cm and the base 10 cm thick. A unique type of construction, worked out in co-operation with Prof. C. I. Gunness of the Department of Agricultural Engineering, was employed, which made the total cost of installation, including excavation, comparatively low—$370. The walls and partitions were cast in molds and were made in the winter when field work could not be done. It was necessary to build a form only for the base, and that consisted of only 2 x 4's and partition strips. The joints were made tight with asphalt roofing cement, and the interior of each tank was given two coats of asphalt paint.

A crop of Japanese millet was grown in the frames in 1933 (Fig. 2)

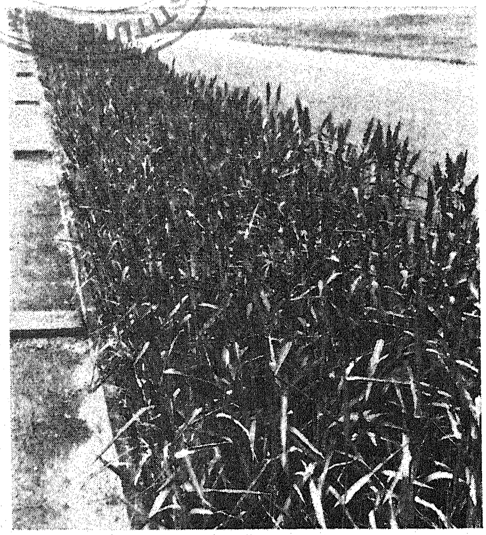

FIG. 2.—Japanese millet growing in concrete tanks at Massachusetts Experiment Station.

to test the uniformity of soil conditions. The following constants, expressed as percentages of the mean yield, were obtained by Bessel's formula:

	Probable error, single yield	Probable error, mean yield
Treated singly	±4.27	±0.59
Treated by adjacent 2's	±3.93	±0.78
Treated by adjacent 5's	±3.36	±1.06

A. B. BEAUMONT, *Massachusetts State College, Amherst, Mass.*

A SIMPLE METHOD OF THRESHING SINGLE OAT PANICLES

AFTER various methods had been tried with different degrees of success, it has been found recently that single oat panicles may be threshed both rapidly and satisfactorily by hand simply by using a light-weight, close-fitting leather glove. If one is right-handed a glove on the right hand is sufficient. The straw or stem of the panicle is gripped firmly between the thumb and forefinger of the left hand, and the spikelets are stripped from the rachis between the thumb and forefinger of the right hand. If the material is reasonably dry the kernels can be threshed from their glumes satisfactorily simply by rolling and kneeding them between thumb and fingers of the gloved hand.

In stripping, as well as in threshing the seed after stripping, the hands should be held over a grain laboratory pan to prevent loss. After the kernels are threshed they are dropped into the pan and the chaff is blown out by a few puffs of the breath. If some of the spikelets are inclined to remain together, they can usually be separated rather easily by use of both hands. The use of a laboratory pan is recommended as it enables one to pour the threshed seed into envelopes.

Several kinds of gloves have been tried in threshing oats, but only strong leather gloves of light weight have proved satisfactory. Cloth, or part cloth, gloves are unsuitable, as the oat kernels hang to the cloth, endangering mixture, and the chaff penetrates the glove, resulting in irritation to the hands. Furthermore, a light-weight leather glove does not seriously hamper one's using a pencil to label envelopes.

By the use of a glove it was possible for one man to thresh, place in envelopes, and number from 100 to 150 oat panicles per hour—a speed hardly possible with any other method or equipment in general use.—F. A. COFFMAN, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

THE TOXICITY OF *CROTALARIA SPECTABILIS* ROTH TO LIVESTOCK AND POULTRY

Crotalaria spectabilis Roth was introduced into the United States a number of years ago by the Bureau of Plant Industry, U. S. Dept. of Agriculture. It is a valuable leguminous cover crop for much of the southeastern states area. The question of its toxicity was not considered, because of its lack of promise as a forage crop, although the genus *Crotalaria* is known to contain species that are toxic, as well as others that are non-toxic.

Chickens brought to E. F. Thomas, formerly assistant veterinarian with the Florida Agricultural Experiment Station, for post-mortem examination in December, 1931, showed lesions that were not typical of any of the ordinary pathological conditions previously encountered. Seeds of *C. spectabilis* were found in the crop and gizzard. Controlled feeding experiments[1] demonstrated conclusively that as few as 80 seeds would kill a hen. Other experiments showed that chickens confined in a yard where this plant was bearing ripe seeds would eat sufficient seeds to kill them.

In another investigation conducted jointly by the Division of Forage Crops and Plant Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Departments of Agronomy and Animal Husbandry of the Florida Agricultural Experiment Station, in which the relative palatabilities of several of the species of *Crotalaria* were being compared in the form of dry roughage, only three cattle (yearlings) out of 19 head, were observed to eat *C. spectabilis* hay in any quantity. These three animals died. It has been seen that small amounts may be taken without actually killing an animal. Three mature cows consumed a total of 12 pounds of the hay in one test without the appearance of any symptoms of poisoning. Two cows were observed to eat some leaves of *C. spectabilis* when the plants were in the early bloom stage without apparent injury.

The most important symptoms of the poisoning were complete loss of appetite, sluggishness, bloody feces, mucous nasal discharge (sometimes bloody), and rapid but weak heart action. The post-mortem lesions include petechial hemorrhages in the subcutaneous and mesenteric fat, lungs, trachea, gall bladder, urinary bladder, and pericardium. Endocarditis, myocarditis, and epicarditis were observed in all three animals. The liver showed fine red mottling. The spleen seemed to be enlarged. The mucous membrane of the abomasum was edematous. The submucosa of the small intestine showed ecchymoses and petechial hemorrhages. Blood and blood clots were present in the lumen of the large intestine.

Final proof of the toxicity of *C. spectabilis* hay to cattle was obtained in December, 1933. A 300-pound steer was drenched over a 4-day period with a total of 9.5 pounds of artifically dried hay that had been ground and suspended in water. Death occurred on the evening of the fourth day. The symptoms and lesions corresponded with those observed in the yearling cattle during the preceding winter.

[1] THOMAS, E. F. The toxicity of certain species of *Crotalaria* seed for the chicken, quail, turkey, and dove. Jour. Amer. Vet. Med. Assoc., 85: 617–622. 1934.

After this proof of the toxicity of the plant, extracts were prepared from the seeds, the leaves, and the stems, and their toxicity studied. Identical lesions were produced in chickens by the use of whole seeds and by the *extract of the seeds, leaves, or stems*. This demonstrated that the toxic principle had been isolated. The extract had alkaloidal properties.[2] Further experiments then were outlined testing the toxicity of this material with various animals. Rats, rabbits, dogs, chickens, and cattle have proved susceptible to this toxic principle. There is little doubt that any other domestic animal that might eat a sufficient portion of this plant would be poisoned by so doing. Its low palatability, however, makes such cases rare.

Other species under observation during the fall of 1931 and of 1932 included *C. incana* L., *C. intermedia* Kotschy, *C. lanceolota* E. Mey, *C. usaramoensis* Baker, *C. anagyroides* HBK., and *C. grantiana* Harvey, all of which were eaten in considerable amounts and without any indications of harmful effects. *C. striata* D. C., previously accused elsewhere of possessing toxic properties, was not eaten in appreciable quantities on the station farm, but it has been reported eaten with impunity by cattle on a number of farms in Florida.—E. W. THOMAS, W. M. NEAL, and C. F. AHMANN, *Florida Agricultural Experiment Station, Gainesville, Fla.*

COMMENTS ON THE WHOLE WHEAT MEAL FERMENTATION TIME TEST

IN a recent issue of this JOURNAL (Vol. 27, pages 241–250), under the caption, "Observations on the Whole Wheat Meal Fermentation Time Test", Dr. E. G. Bayfield, reports some studies made on the fermentation time test as outlined by the writers and compares it with the Pelshenke method. Both of these tests were designed to evaluate the gluten strength of wheat. Dr. Bayfield attempts to appraise these two procedures by reporting the results of some 46 samples, which would require about one day's work, and finally reaches the conclusion that the Pelshenke procedure is to be preferred because the larger dough balls used by Cutler and Worzella stick to the sides of the beakers.

In 6 years' experience with the whole wheat meal fermentation time test, in which the originators of this test have run over 20,000 separate samples of soft and semi-hard wheats, they have not had one dough ball stick to the side of the beaker. Consequently, Dr. Bayfield's paper has been read and studied with some care and the writers feel obliged to answer it in order to avoid any misunderstanding on the part of readers of the JOURNAL, especially plant breeders.

It should be noted at the outset that the wheat meal fermentation time test and the Pelshenke test are both modifications of the Saunder's test which was reported in the *Journal* of the Institute of Agricultural Botany (Vol. 2, 1928). The writers were the first in America to modify the Saunder's test so that it might be applicable to testing the gluten strength of small plant breeding samples of wheat,

[2]NEAL, W. M., AHMANN, C. F., and RUSOFF, L. L. The isolation and some properties of an alkaloid from *Crotalaria spectabilis* Roth. Paper presented before the Amer. Chem. Soc., St. Petersburg, Fla. March 27, 1934. In press.

while Pelshenke of Halle, Germany, did the same thing in Europe. These investigators, working independently and unknown to each other, discovered and published tests which involved somewhat different procedures.

Dr. Bayfield did not follow either the Cutler-Worzella or the Pelshenke procedures, and consequently, should not expect to obtain results that would correlate with those obtained by the authors of these tests.

The original Pelshenke test includes both a protein content test and a fermentation test for each sample. The gluten quality is then obtained by dividing the "time" by the amount of protein and the resulting figure is designated as "specific protein quality". This is emphasized as an important feature of the Pelshenke test because the end result takes into account both quantity and quality of gluten. Furthermore, Pelshenke derives the 5-gram dough ball by first kneading a 10-gram dough ball and then dividing it into two equal parts. Each of these parts was then placed in a low form, 150-cc beaker in 75 cc of water and held at 32° to 33°C in a fermentation cabinet.

The Cutler-Worzella procedure, on the other hand, involves only the fermentation feature, the protein test not being included, and the results are reported in minutes. Triplicate tests consisting of 10-gram dough balls are made separately in low form, 150-cc beakers in 80 cc of water held at 26.7°C. The writers also recommended the use of a 5-gram and a 3.5-gram dough ball. In using these dough balls, however, the amount of yeast suspension, the size of the beaker, and the amount of water in the bath had to be reduced. Furthermore, a 10% variability rule is observed as a basis of agreement in the results obtained.

In carrying out his tests, Dr. Bayfield departed from one or both of the two procedures he appraises in the following details:

1. Temperature of the water bath and fermentation cabinet.
2. Disregard of the "specific protein quality" number of the Pelshenke test.
3. Proper granulation of the wheat meal.
4. Making the Pelshenke dough ball.
5. Replication of dough ball tests.
6. Non-observance of the 10% variability rule.

Inasmuch as Dr. Bayfield did not follow either the Cutler-Worzella or the Pelshenke procedure in detail his results cannot have any significance as a basis for appraising these two methods.

Once again the authors of the fermentation time test are impelled to caution users of this test, as in former papers, that the test "is not fool-proof and must be conducted according to prescribed methods if a high degree of satisfaction is to be achieved", and that "it will prove a valuable guide to gluten strength when applied with due regard for care and attention to details."

We believe that had Dr. Bayfield followed the prescribed procedure, he like many other experimenters, would have obtained equally satisfactory results.—G. H. CUTLER AND W. W. WORZELLA, *Purdue University Agricultural Experiment Station, Lafayette, Indiana.*

FURTHER COMMENTS ON THE WHOLE WHEAT MEAL FERMENTATION TIME TEST

A pre-publication review of the above note by Professor G. H. Cutler and Dr. W. W. Worzella commenting on "Observations on the Whole Wheat Meal Fermentation Time Test" has been made possible through the courtesy of the Editor of this JOURNAL.

The writer believes that no benefit will result from an extended exchange of opinions unsupported by adequate data, but it is desired to correct any misleading impressions which may possibly result from reading the criticisms by Cutler and Worzella regarding paucity of data. This criticism was also made by Professor Cutler after reveiwing the original manuscript before it was presented for publication in this JOURNAL. The writer, in a personal communication (Jan. 15, 1935) to Professor Cutler, replied that the conclusions were based on some 2,000 tests and not merely on the 46 samples given as examples in the paper published as a preliminary report.

Since then, much additional data have been accumulated. Part of this material has been accepted for publication in *Cereal Chemistry* under the title, "Soft Winter Wheat Studies. IV. Some Factors Producing Variations in Wholemeal 'Time' Data". Furthermore, a collaborative study of the test was undertaken in conjunction with several prominent cereal chemists in the United States and Canada. The resulting report, "A Collaborative Study on the Use of the Wheat Meal 'Time' Test With Hard and Soft Wheats", is now in an advanced stage of publication. These additional data support the earlier conclusions regarding size of dough ball previously presented in this JOURNAL as a preliminary report. In fact, it is believed that a 4-gram dough ball should be used with the 150-cc form beaker and 80 cc of water if the entire range in strength existing in North American wheats is to be tested.—E. G. BAYFIELD, *Ohio Agricultural Experiment Station, Wooster, Ohio.*

BOOK REVIEWS

WEEDS

By W. C. Muenscher. New York: Macmillan Company. 577 pages, illus. 1935. $6.00.

THIS book is a botanical approach to the study of weeds in northern United States, containing keys, descriptions, and well-executed illustrations by which anyone would have no difficulty in identifying a particular weed plant. Included in the list are not only common native plants, but also some cultivated plants which have escaped and become troublesome. A fuller conception of the scope of the book may be gained by mentioning that the horsetails, various ferns, and violets are to be found among the plants listed.

The plants are arranged alphabetically under their scientific names by families, the families being in turn arranged according to botanical phyllogenetic conceptions. Following the scientific and common names come a description of the methods and places of distribution, description of the plant, and means of control.

A chapter on the dissemination and importance of weeds occupies 39 pages; a chapter on weeds of special habitats, as weeds of lawns, pastures, hayfields, gardens, grain fields, cranberry bogs, and rice fields, occupies 13 pages; a chapter on weed control occupies 17 pages; a chapter on chemical weed control occupies 21 pages; 438 pages are devoted to plant descriptions, keys, and specific control measures; and 48 pages are used for glossary, literature, references, and index.

The treatment is accurate, and the book is well-indexed and well-referenced. Unexpected yet helpful bits of information abound, such as a table of plants likely to harbor diseases of common crop plants, a table of poisonous weeds, and weeds used as medicinal plants. It will be found a valuable publication not only by the student and teacher, but also by the extension worker, the farm bureau agent, and the farmer. (H. B. T.)

PLANT LIFE

By D. B. Swingle. New York: D. Van Nostrand Co., XIV + 441 pages, illus. 1935. $3.00.

ALTHOUGH designated as "A Textbook of Botany," this book will be found interesting reading by many. It is designed to fill the need for covering the field of botany in one semester. In presentation of material, the method is used of first arousing the curiosity of the reader and then satisfying it. The entire work is centered around the life processes in plants. The book is adequate and well printed. (H. B. T.)

AGRONOMIC AFFAIRS

AN AMERICAN POTASH INSTITUTE

AMERICAN producers and importers of potash salts announce the organization of the American Potash Institute, Inc., to be established in Washington at an early date with Dr. J. W. Turrentine, formerly in charge of the potash researches of the Bureau of Chemistry and Soils, as President and G. J. Callister, Director of the Agricultural and Scientific Bureau of the N. V. Potash Export My., Inc., as Secretary. The Institute expects to cooperate with federal and state agencies in carrying on research and experimental work in the United States, Canada, and Cuba and with the National Fertilizer Association and other scientific and trade organizations. It is contemplated that branch offices of the Institute will be set up at Atlanta, Ga.; Lafayette, Ind.; San Jose, Calif.; and Hamilton, Ontario.

MEETING OF THE NORTHEASTERN SECTION OF THE SOCIETY

THE following program has been arranged for the summer meeting of the Northeastern Section of the American Society of Agronomy to be held in Maine July 16 to 18.

TUESDAY, JULY 16, HIGHMOOR FARM, MONMOUTH, MAINE

Morning

Visiting experimental plats at Highmoor Farm. (Fertilization and breeding of sweet corn, production of foundation seed potatoes under cloth cages, etc.)

Afternoon

Enroute to University of Maine, Orono, Maine, visiting pasture fertilization plats on the way.

Tour of campus and University Farm.

Banquet and business meeting.

WEDNESDAY, JULY 17

Morning

Enroute to Aroostook Farm, Presque Isle, Maine.

Afternoon

Visiting experimental plats at Aroostook Farm. (Potato fertilization and potato breeding.)

Evening

Meeting of Agronomy Extension Specialists.

THURSDAY, JULY 18

Morning

Visiting experimental plats at Aroostook Farm. (Potato disease control; small grain variety tests.)

Afternoon

Tour of selected farms in Aroostook County, including inspection of farm and truck storage houses.